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UNCERTAINTY, BANKING SECTOR AND  
FINANCIAL FRICTIONS

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Thesis submitted to the Department of Economics, Mathematics and Statistics of  
Birkbeck, University of London  
for the degree of Doctor of Philosophy

London, June 2017

## **Declaration**

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## **Abstract**

Uncertainty is an important determinant of economic developments at both micro and macroeconomic levels. The main objective of this thesis is to examine the effects of economic and model uncertainty, paying close attention to financial factors as a key mechanism that propagates and amplifies business cycle movements.

The first part of the thesis studies the impact of uncertainty on bank assets portfolios allocation. In chapter 1 I do this empirically by estimating a set of vector autoregression models. I show that a positive shock to uncertainty leads to reallocation of portfolios by commercial banks: they reduce issuance of business loans, while increasing the stock of safe assets - cash and Treasury and agency securities. I also demonstrate that when risk, uncertainty and balance sheet factors are controlled for, business loans decrease after monetary tightening, what allows to resolve the puzzle raised by den Haan et al. (2007) that business loans increase following monetary contraction.

In chapter 2 I examine the relationship between economic uncertainty and asset portfolio allocation of banks in a theoretical model. The model incorporates a portfolio-optimizing banking sector facing non-diversifiable credit risk, where banks' attitude to risk and expected profitability help to explain the endogenous movements of the risk premium. The premium charged by risk-averse banks provides self-insurance from profitability reduction brought about by heightened uncertainty about entrepreneurial productivity. Financial accelerator mechanism amplifies the portfolio reallocation effect of uncertainty shock.

In the second part of the thesis I study how financial frictions affect robustness of monetary policy rules in New Keynesian models in case of model uncertainty. I demonstrate that when there is uncertainty about what type of financial frictions is at work, a policymaker exposes economy to risks of significant welfare losses by using a reference model without frictions as an economy representation.

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# Introduction

Uncertainty is an inherent feature of economic activity. The results of most economic operations and developments are uncertain. This pertains, for example, to profitability outcomes of economic agents, to behaviour of counterparties or to the future dynamics of the main macroeconomic aggregates. Besides, due to the fact that economic models are necessarily a simplification of reality, there is uncertainty about which model represents the economy in the best way. This latter type of uncertainty is commonly referred to as model uncertainty. The two types of uncertainty that I deal with in this dissertation are uncertainty about future developments of economy, referred to as economic uncertainty hereinafter, and model uncertainty.

There is a distinction between the concepts of risk and uncertainty in economic literature. According to Frank Knight, who introduced this differentiation<sup>1</sup>, the term 'risk' is used in the cases, when the degree of unknownness could be quantified probabilistically. Otherwise the term 'uncertainty' is used. This difference is, however, blurred in macroeconomic literature today, given that there are approaches to measure uncertainty in probabilistic terms. This is, for example, a commonly used VIX/VXO index as an uncertainty measure that captures the implied volatility of stock market. Time-varying volatility of economic variables is also frequently referred to as a source of uncertainty<sup>2</sup>. Following this established practice of macroeconomic literature, I use the term 'uncertainty' in its broad sense in this dissertation, meaning that uncertainty captures, among others, the case of time-varying volatility.

Economic uncertainty plays a crucial role in affecting economic developments. The changes in volatility and uncertainty are shown to be quantitatively significant factors in business cycle movements and a key element in successful explanation of aggregate fluctuations<sup>3</sup>. Notably, it has been demonstrated that uncertainty had a critical effect on various variables during the financial crisis of 2007-2009<sup>4</sup>. The negative effect of heightened uncertainty on economic activity is also found in microeconomic data<sup>5</sup>.

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<sup>1</sup>In Knight's words, "There is a fundamental distinction between the reward for taking a known risk and that for assuming a risk whose value itself is not known. It is so fundamental, indeed, that ... a known risk will not lead to any reward or special payment at all" (Knight, 2009).

<sup>2</sup>See, among others, Bloom (2009), Bloom et al. (2016), Fernandez-Villaverde et al. (2011), Born and Pfeifer (2014), Cesa-Bianchi and Fernandez-Corugedo (2015) on this.

<sup>3</sup>The negative effect of uncertainty on aggregate variables is found in Romer (1990), Ramey and Ramey (1995), Bussiere and Mulder (2000), Bachman et al. (2010), Popescu and Smets (2010), Baker and Bloom (2011), Drechsler and Yaron (2011), Novy and Taylor (2012), Mody et al. (2012), Alessandri and Mumtaz (2014), Born and Pfeifer (2014).

<sup>4</sup>See, for example, Stock and Watson (2013) and Christiano et al. (2014) on this.

<sup>5</sup>Microeconomic evidence suggests that heightened uncertainty has negative impact on firms level investment

Financial frictions is another critical factor that determines the dynamics of economic aggregates. A number of studies reveal the empirical relevance of financial accelerator mechanism<sup>6</sup>. Other works demonstrate the evidence supporting significance of collateral constraints as a factor behind aggregate fluctuations<sup>7</sup>, while some papers emphasize the importance of disruptions of financial intermediation<sup>8</sup>, contagion transmission<sup>9</sup>, asset price bubbles<sup>10</sup> or credit shocks<sup>11</sup>. The case of the recent financial crisis of 2007-2009 and its causes is especially important given its adverse and far-reaching consequences, and it has been acknowledged that financial factors have contributed significantly into the recent economic decline<sup>12</sup>. As a result, various models with distinct types of financial frictions emerged in an attempt to capture the relevant economic mechanisms that represent economy at work. Thereby the issue of model uncertainty arises. This issue is especially relevant in turbulent times, when uncertainty is high, as it becomes more complicated to ascertain which amplification mechanisms are conducive to economic fluctuations.

Taking into account the critical role that financial frictions and uncertainty play in determining the path of economic developments, a natural question of their interaction arises. This interaction is interesting, because it opens the space for taking into account the important channels, via which financial and uncertainty conditions have an effect on real activity. The first channel is procyclicality of capital markets, or allowing asset prices to have an impact while feeding back to real economy. A mechanism that delivers this outcome could arise due to asymmetric information and agency frictions. Specifically, in bad times, when firms' balance sheets are weak and the collateral value is low, the cost of external finance goes up, what results in decreasing availability of funds and amplification of shocks hitting the real sectors of economy<sup>13</sup>. Elevated uncertainty about firms' productivity exacerbates frictions associated with asymmetric information and has a potential to work in two directions. First, when future returns are subject to uncertainty, companies are likely to change their demand for input factors of production; this pattern is captured by the real options or wait-and-see effect of uncertainty, suggested in theoretical literature by Bernanke (1983) and Brennan and Schartz (1985)<sup>14</sup>. This channel is studied empirically and theoretically in Alfaro

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– see Leahy and Whited (1996), Guiso and Parigi (1999), Bloom, Bond and Van Reenen (2007), Bond et al. (2005), Stein and Stone (2010), Baum et al. (2010). Negative effect on investment of industries is shown in Caballero and Pindyck (1993), Huizinga (1993), Ghosal and Loungani (1996). Carol and Dunn (1997), Foot et al. (2000) and Bertolla et al. (2005) demonstrate that consumers' spending also react negatively influenced by an elevated uncertainty.

<sup>6</sup>Bernanke et al. (1999), Carlstrom and Fuerst (1997), Mody and Taylor (2004), Aliaga-Diaz and Olivero (2010), Peersman and Smets (2005), Almeida et al. (2006), and Cavalcanti (2010).

<sup>7</sup>See among others, Fazzari et al. (1988), Gertler et al. (1991), Gilchrist and Himmelberg (1995), Hubbard et al. (1995), and Kashyap et al. (1994).

<sup>8</sup>See Adrian and Shin (2010), Brunnermeier and Pedersen (2009), Gertler and Karadi (2011), and Balke and Zeng (2013).

<sup>9</sup>See Mendoza and Quadrini (2010).

<sup>10</sup>See Farhi and Tirole (2011), and Martin and Ventura (2011).

<sup>11</sup>See Christiano et al. (2008), and Del Negro et al. (2010) for details.

<sup>12</sup>See, among others, Stock and Watson (2012), Caldara et al. (2016), Balke and Zeng (2013), Krishnamurthy (2010), Geanakoplos (2009), Chatterjee (2010) and Peralta-Alva (2011 a,b).

<sup>13</sup>This transmission mechanism draws from financial accelerator hypothesis of Bernanke et al. (1999).

<sup>14</sup>I discuss various theoretical mechanisms via which uncertainty has an impact on real economy in more details in the current section below.

et al. (2016), who demonstrate that in presence of financial frictions the negative impact of uncertainty shocks on investment and hiring nearly doubles. In addition to real options effect, they emphasize the significant impact of uncertainty on firms' cash hoarding and debt cutting to hedge against future shocks, what reduces investment and hiring further. The importance of frictions in presence of uncertainty is corroborated in this study by the evidence that the strongest effect of elevated uncertainty is attained for the most financial constrained firms. Second, along the lines with Arellano et al. (2010) and Gilchrist et al. (2011), there's a downward pressure on the supply of capital when uncertainty is heightened, as the value of the collateral becomes more uncertain. An additional amplification mechanism due to misperception of uncertainty and risks by financial intermediaries is suggested by Borio et al. (2001). This paper argues that in good times lenders might underestimate the risk, and overestimate it in bad times, thereby the procyclical credit issuance emerges. The other ways how uncertainty could bring about amplification within the asymmetric information setup and contribute to capital markets' procyclicality are assuming non-linear preferences of financial intermediaries, their time-varying risk-aversion or institutional constraints (for example, capital requirements) that they have to abide by.

Second, uncertainty might emerge endogenously under financial frictions. For example, relationship banking, that is found to be especially relevant for business lending<sup>15</sup>, works to reduce informational asymmetries between borrowers and lenders. In bad times, when banking activity slows down, the relationship banking is also affected negatively, what reduces the flow of information and thereby raises uncertainty, in this case microeconomic uncertainty, about financial conditions of borrowers.

Empirical evidence provided by Alessandri and Bottero (2016) demonstrates the relevance of the supply-side effects of uncertainty. This study shows that the reduction of credit volumes in times of elevated uncertainty is not a mere by-product of the choices of borrowers; also lenders contribute to this reduction by being more hesitant about credit issuance and by tightening their lending standards, when uncertainty is high. Alessandri and Bottero (ibid.) also stress the importance of banks' balance sheets structure, as the decisions about business loans' issuance made by low capitalized banks are affected by elevated uncertainty more than the same type of decisions of well-capitalized banks. Finally, Aastveit et al. (2013) and Alessandri and Bottero (ibid.) find that uncertainty weakens the bank lending channel of monetary policy, as banks become less responsive to fluctuations in short-term interest rates facing elevated uncertainty. This multiple aforementioned considerations and literature findings corroborate the relevance of interactions between uncertainty and financial frictions as a topic of study.

Given this, the objective of this dissertation is to study the macroeconomic effects of uncertainty under financial frictions. Its contribution is the analysis of the portfolio reallocation effects of economic uncertainty in the banking sector and examination of the effect of financial frictions on robustness of monetary policy in the case of model uncertainty.

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<sup>15</sup>Hoshi et al. (1991), Petersen (1999), Petersen and Rajan (1994), Chakraborty and Charles (2006) and Bharath et al. (2011) provide empirical evidence on that.

The main hypothesis of this thesis is that uncertainty has a non-trivial effect on the workings of economic mechanisms involving financial factors. The first part of the dissertation deals with the effects of uncertainty shocks on loan issuance by the banking sector. The second part is devoted to study the role that uncertainty about what type of financial frictions is at work has on robust way to implement monetary policy.

In the first part of the thesis I study financial frictions stemming from the banking sector activities. Bank credit is a critical factor of facilitating economic activities and promoting economic growth. Not only banks act as financial intermediaries, reallocating resources and facilitating transactions in economy, they also create additional means of payment in the form of deposits, when originating new loans, what increases the aggregate nominal purchasing power of the economy. In data bank supply of loans is shown to have a significant effect over the business cycles in the United States, the Euro area and the UK<sup>16</sup>. As suggested by the recent empirical findings, banks continue to play their special role in affecting aggregate activity in the presence of other sources of funding, namely, equity, debt securities and loans from non-banks that have a potential to compensate for the reductions of loan supply. Aldasoro and Unger (2017) show that even though there has been a shift from bank loan supply to other sources of funding from the onset of financial crisis of 2007-2009, the lack of bank loans issuance was a crucial factor that depressed economic activity and prices. Interestingly, negative shocks to the supply of alternative sources of business funding are not found to have a significant effect on aggregate activity in this study. The special role of banks as financial intermediaries is further reinforced by other considerations, including their ability to reduce information asymmetries, delegated monitoring, liquidity insurance and transformation, maturity transformation and relationship lending<sup>17</sup>.

Hence, part 1 of this thesis studies the effects of uncertainty shocks on asset portfolio allocation by banks. Chapter 1 studies the impact of various factors on the issuance of the different types of bank loans - commercial and industrial loans, consumer loans and real estate loans. Two structural breaks are identified in relationships between credit and macroeconomic variables over the sample of data studied - one is associated with the shift of monetary policy in the US to an anti-inflation stance in early 1980's, while the other one is related to the 2007-2009 financial crisis. The estimated set of orthogonalized structural vector autoregressive models takes into account these structural breaks. I include bank capital, credit risk, and uncertainty factors into the models in addition to controlling for macroeconomic variables and indebtedness of the private sector. I employ several measures of economic uncertainty to obtain robust evidence regarding the effects of uncertainty shocks. I use impulse response functions and forecast error variance decomposition to make inference about the impact and relative importance of various factors on the volume of issued bank loans and safe assets' holdings, where the latter is measured by the sum of cash and Treasury and agency securities.

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<sup>16</sup>See, for example, Busch, Schornagl, and Scheithauer (2010); Cappiello, Kadareja, Kok, and Protopapa (2010); de Bondt, Maddaloni, Peydro, and Scopel (2010); Hristov, Hulsewig, and Wollmershauser (2012); Moccero, Darracq Paries, and Maurin, (2014); Altavilla, Darracq Paries, and Nicoletti (2015); Gambetti and Musso (2016).

<sup>17</sup>See Freixas and Rochet (2008) for details.

The positive contribution of chapter 1 is to show that the volume of business loans issued by commercial banks is driven by substantially different set of factors than the volume of consumer loans or mortgages. In particular, in contrast to consumer loans, where the dynamics is determined predominantly by macroeconomic variables' innovations, the issuance of commercial and industrial loans is driven by shocks to uncertainty and credit risk. The volume of real estate loans issued is determined by innovations to uncertainty and capital ratio of banks in the short term, and by innovations to inflation, leverage of the private sector and nominal interest rate in the medium and long terms. I resolve the puzzle raised by den Haan et al. (2007) that business loans increase following monetary tightening. I find that controlling for risk and uncertainty factors reveals the negative impact of monetary contraction on business loans issuance, what corroborates the existence of the bank lending channel of monetary policy.

Chapter 2 analyzes the relationships between bank portfolio allocation and economic uncertainty in a theoretical model. I set up a dynamic stochastic general equilibrium model with financial accelerator mechanism incorporated along the lines of Bernanke et al. (1999) to analyse the impact of idiosyncratic uncertainty shocks on business loan volumes issued by the portfolio-optimizing banking sector. Uncertainty is measured by the time-varying variance of idiosyncratic component of entrepreneurial productivity. I set up the structure of the optimal debt contract to ensure that the lending rate is non-contingent on shock values, such that the resulting profit of banks arises is not necessarily zero. Precautionary behaviour of banks that emerges due to their willingness to self-insure against future profitability reductions allows to explain an additional share of increase of lending rates and of credit issuance reduction in response to a positive uncertainty shock. Financial accelerator mechanism amplifies the portfolio reallocation effect of uncertainty shock, as increased external finance premium reduces entrepreneurial demand for capital, putting downward pressure on real price of capital and on borrowers' net worth, what depresses the demand for capital further.

Chapter 3 studies how financial frictions affect robustness of monetary policy in DSGE models in the case of model uncertainty. The types of frictions I consider are financial accelerator and housing and collateral constraints. Modeling monetary policy in terms of optimized interest rate rules, I find that welfare-maximizing policies for the models with financial frictions are robust to model uncertainty. Policy rule optimal for the basic New Keynesian model is not robust. The normative contribution of this chapter is to show that when there is uncertainty about what type of frictions is at work, a policymaker exposes economy to risks of significant welfare losses by using a reference model without frictions as economy representation. Hence, it is important to take into account financial frictions in the monetary policy analysis in case of model uncertainty. Using fault tolerance approach I find that a modified policy rule optimal for the basic New Keynesian model becomes robust, if it is modified to incorporate the responses of interest rate to fluctuations in output.

I use different research approaches in this thesis. In chapter 1 a set of structural vector autoregression models is estimated on uncertainty, macro and financial data. In chapter 2 I use recursive macroeconomic method and focus on how banks can achieve optimality,

when credit issuance is subject to asymmetric information, is risky and is made under uncertainty. I solve the general equilibrium model up to the third-order by using the perturbation method and compute impulse response functions as deviations from ergodic means of variables' distributions. I use pruning procedure to deal with the problem of explosive behaviour of simulated data in high-order perturbations. In chapter 3 I employ welfare-maximization techniques to evaluate welfare costs and find optimized policy rules for the set of New Keynesian models; I also use the fault tolerance approach to draw normative conclusions about the design of monetary policy rules adopted in the models of New Keynesian framework.

#### *Selected literature review*

In this section I first review the literature on various transmission mechanisms of uncertainty. Then I discuss research that investigates the impact of uncertainty under financial frictions.

Theoretical literature suggests several transmission mechanisms via which uncertainty makes its impact on economic activity<sup>18</sup>. First, these are Oi-Hartman-Abel effects of uncertainty on firms' investments (Oi, 1961; Hartman, 1972; Abel, 1983). Under flexible prices setup, if the expected marginal revenue product of capital is convex in output prices and in total factor productivity, greater uncertainty about output and TFP raises the demand for capital. Hereby a positive effect of uncertainty shocks on investment arises. In case of sticky prices, when all the demand has to be met and prices are not adjusted perfectly, an inverse effect emerges. Marginal profit is convex in relative prices, and therefore, setting the price too high relative to the aggregate price implies selling lower quantity at a higher profit per unit. Because setting too low price entails selling more goods, but at a higher loss, firms choose to set higher prices. In the case of elevated uncertainty this increases markups over marginal costs, what puts a downward pressure on demand and output<sup>19</sup>. According to Bloom (2014), this transmission channel of uncertainty shocks works, when firms are able to expand and contract easily in response to news, with the effect being stronger in medium and long run, than in the short run. In the theoretical model in chapter 2 the capital is predetermined and labour input can be adjusted, what allows elevated uncertainty to have positive effects on investments according to Oi-Hartman-Abel transmission mechanism.

Second, there are real option effects of uncertainty, which arise due to partial irreversibility of investments (Bernanke, 1983; Brennan and Schwartz, 1985). It is argued that investment opportunities could be regarded as options. Higher uncertainty about returns of investments raises the option value of delay, i.e. a firm prefers to wait before hiring and making investments in order to avoid a costly mistake. As a result, in presence of adjustment costs that make reverse of investment and hiring expensive, firms become cautious and find it optimal to wait, when uncertainty is high.

In a similar fashion, elevated uncertainty might cause households to delay their consumption of durable goods. The option value of waiting is high in the case of heightened uncertainty about future income. Eberly (1994) demonstrates that households postpone their

<sup>18</sup>See Bloom (2014) and Born and Pfeifer (2014) for details.

<sup>19</sup>See Pfeifer et al. (2012) for the discussion of Oi-Hartman-Abel effects in the open economy setup.



decisions about buying housing, cars and other types of durable goods easily. That heightened uncertainty makes expenditure on households' durables less responsive to changes in demand and prices, has been shown in Foote et al. (2000) and Bertola et al. (2005).

Apart from the direct negative impact of uncertainty on investments, hiring and consumption according to the real option transmission mechanism, wait-and-see mechanism of uncertainty implies, that in making their decisions households and firms become less sensitive to changes in business conditions. Bloom (2014) argues that this makes countercyclical economic policy less effective and suggests that stimulus needs to be more aggressive in order for policy actions to stabilize economy to be efficient. Born and Pfeifer (2013), on the other hand, show that the role of policy uncertainty in driving business cycle fluctuations is small.

In the theoretical model that I build in chapter 2 I introduce quadratic type of adjustment costs, i.e. the costs that increase in the squared rate of investment. This allows me to 'switch off' the real option transmission mechanism of uncertainty in its impact on investment, because this type of effect is not generated under this type of smooth "convex" adjustment costs (Dixit and Pindyck, 1994; Abel and Eberly, 1996). Additionally, I assume constant returns to scale technology, what implies that choice of investment today has no impact on returns of investments tomorrow, what also closes the option value channel. This allows me to focus on analyzing the effects of the precautionary mechanism of banks as the main amplification mechanism in the theoretical model.

The third channel via which uncertainty makes its impact on economic activity, is risk aversion and risk premia effects; this channel encloses four sub-channels. First, in presence of financial constraints elevated uncertainty increases firms' borrowing costs, what reduces growth (Arellano et al., 2010; Christiano et al., 2014; Gilchrist et al., 2011). This happens due to investors requiring a higher risk premia that emerges because uncertainty increases the probability of default. Second, risk premia transmission mechanism arises, if the behaviour of economic agents features "ambiguity aversion" (Hansen et al., 1999; Ilut and Schneider, 2011). When agents have pessimistic beliefs, they act as if the worst scenario will unfold. As increased uncertainty deteriorates the worst possible outcome, agents reduce their investment expenditures and hiring. In contrast to this, a positive impact of increased uncertainty is found, if the beliefs of economic agents are optimistic (Malmendier and Tate, 2005). Third, income uncertainty reduces consumption due to precautionary saving effect, as argued by Bansal and Yaron (2004). The strength of this effect is ambiguous in the long run, given that higher saving might contribute to increase of investment. As argued by Fernandez-Villaverde et al. (2011), in case of open economies the effect of this channel on domestic economy growth is negative, as increased consumers' savings flow to foreign economy. In closed economies the negative effect of uncertainty via this transmission channel is reached by allowing for nominal rigidities. Leduc and Liu (2012), Basu and Bundick (2011) and Fernandez-Villaverde et al. (2011) show that if prices cannot be adjusted downwards to clear the markets, elevated uncertainty leads to economic decline even in case of closed economy. Forth, the importance of precautionary mechanism is shown, when there is lack

of diversification of the companies' chief executive manages, i.e. when their personal assets and human capital are tied in one company. Panousi and Papanikolaou (2012) demonstrate that CEOs are more cautious in making decisions about investment in this case, behaving like risk-averse agents.

The transmission channel suggested in the theoretical model in chapter 2 of the thesis – precautionary mechanism of financial intermediaries in response to elevated uncertainty – has to do with the risk aversion and risk premia type of impact of uncertainty. Specifically, this mechanism works via raising the cost of external finance, which is reinforced by the motive of the banking sector to self-insure against future profitability reduction due to increased uncertainty.

While all the aforementioned effects of uncertainty are shown to produce significant contractionary effects in partial equilibrium, their impact in general equilibrium is less strong. This happens due to the fact that in general equilibrium prices and interest rates adjust, what reduces the impact of the transmission mechanisms. Bachmann and Bayer (2013) demonstrate that the importance of uncertainty shocks increases by 50%, when the general equilibrium channel is closed. Basu and Bundick (2012), on the other hand, find that in presence of nominal rigidities and zero lower bound constraining the central bank, the effects of uncertainty shocks in general equilibrium are significant.

Even though the topic of relationship between uncertainty and economic activity is central in the current research agenda, the impact of uncertainty under financial frictions has been analyzed within a limited number of studies so far. Most of the papers focus on frictions characterizing the demand side of the financial sector. Among those, Gilchrist et al. (2014) show the difference in implications of an increase in uncertainty for equity holders and for bond holders in both empirical and theoretical settings. Using the debt contract structure similar to Cooley and Quadrini (2001), they demonstrate that elevated idiosyncratic uncertainty induces increasing cost of capital, what puts upward pressure on the costs of bond holders, whereas the impact on the costs of equity holders is negative. Additional TFP reduction in response to uncertainty shock is brought about by low credit supply, what hinders efficient capital reallocation. Christiano et al. (2014) analyse the role of idiosyncratic uncertainty, in their terminology - risk shocks, in an estimated DSGE model featuring financial accelerator a la Bernanke et al. (1999). They demonstrate that increased uncertainty makes a crucial contribution to the business cycles fluctuations in the US. In contrast with two previous studies, Balke et al. (2013) analyse the effects of both micro- and macroeconomic uncertainty shocks in presence of credit frictions utilizing theoretical model with agency costs. This study shows that when prices are sticky, positive shocks to uncertainty induce the decline of economic activity, which is amplified by financial accelerator mechanism. Similarly, Cesa-Bianchi and Fernandez-Corugedo (2014) examine the impact of two types of uncertainty: micro- and macrouncertainty. This study uses a financial accelerator framework as formulated by Faia and Monacelli (2007) and demonstrates that nominal rigidities and financial accelerator amplify the negative effect of elevated uncertainty on economic activity.

There is relatively little research of the effects of uncertainty stemming from the supply side of the financial sector. Among these papers, Bonciani and van Roye (2016) focus on the stickiness in banking retail interest rate as an amplification channel in analyzing the effects of uncertainty shocks. Benes and Kumhof (2015) analyse welfare implications of imposing the bank capital adequacy regulations under heightened uncertainty. Theoretical model in chapter 2 of the thesis also focuses on the impact of uncertainty via the supply side of the banking activity with the focus on the banks' portfolio reallocation between risky and safe assets. I emphasize the role of the banks' precautionary mechanism, which has not been examined so far. In doing this, my analysis is complementary to the studies discussed above.

# Chapter 1

## Bank loan components, uncertainty and monetary transmission mechanism

### 1.1 Introduction

In the course and in the aftermath of the recent financial crisis monetary authorities in many countries have been trying to promote credit growth by adopting various policies, including lowering nominal interest rates. According to the bank lending channel of monetary transmission mechanism, banks are expected to increase loans issuance when the policy stance is easy. This, however, did not happen. Despite the measures undertaken, credit growth in many advanced economies has been predominantly negative for a prolonged period<sup>1</sup>. In this context a finding by den Haan et al. (2007), that commercial and industrial (C&I) loans respond to monetary easing by significant decline, has a special relevance, as it allows to explain (at least, partially) weak or negative credit growth in the conditions of highly accommodative stance of monetary policy. This finding, however, is not in line with the bank lending channel of monetary transmission that has been established as relevant by many works in macro-finance empirical literature<sup>2</sup>.

In this chapter I aim at resolving the puzzle of den Haan et al. (2007) by taking into account various risk and balance sheet factors that are found to be influential in credit market<sup>3</sup>. I conjecture that controlling for economic uncertainty, credit risk, indebtedness of the corporate sector and banks' capital ratio allows to explain the responses of disaggregated loans to monetary policy shocks by avoiding omitted variables bias and to provide a valuable insight to the portfolio behavior of bank loans following various types of shocks.

First, I introduce a baseline vector autoregression (VAR) model<sup>4</sup> that builds upon den Haan et al. (2007). A VAR process for commercial and industrial loans in this specification

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<sup>1</sup>For details see IMF Global Financial Stability Report, October 2013.

<sup>2</sup>See, among others, Bernanke and Blinder (1992), Kashyap and Stein (1995), Kishan and Opiela (2000).

<sup>3</sup>See, among others, Stock and Watson (2012), Banerjee et al. (2015).

<sup>4</sup>I refer to this specification of the model as a baseline model later.

includes three major monetary policy VAR variables - real GDP, inflation and a monetary policy instrument, - and a bank loan measure. In addition to commercial and industrial loans, I analyze dynamic patterns of real estate loans and consumer loans within this benchmark setup. My specification, however, is different from the one in den Haan et al. (ibid.) in several aspects. First, by using several types of Chow tests I formally test the VARs for structural changes in relationships between credit and macroeconomic variables. I identify two structural breaks in the model's parameters: the first one is related to the shift of the US monetary policy to an anti-inflation stance in 1980-1982, and the second one is associated with the financial crisis of 2007-2009. I therefore analyze the dynamic properties of loans over three periods that are separated by the breakpoint dates<sup>5</sup>. Second, I perform robustness checks of monetary policy shock effects by using alternative monetary policy indicators, in particular, nonborrowed reserves of depository institutions and 3 month Treasury bill rate. Third, I analyze the responses of banks' Treasury and agency securities' holdings and total loans to monetary and real activity shocks. Forth, I analyze the dynamic patterns of loans and securities' holdings after the financial crisis of 2007-2009 by making use of monthly data on macroeconomic and financial variables. I find that in the baseline model specification business loans feature positive response to monetary tightening (the result obtained by den Haan et al. (ibid.)) only over the period of 1983-2007; over 1954-1979 and over 2010-2015 all types of loans respond to monetary contraction negatively.

I then augment the model with a set of risk and balance sheet variables that are found to make substantial impact on banks' decisions about loans' issuance. I find that controlling for economic uncertainty, credit risk, indebtedness of the corporate sector and capital ratio of banks allows to resolve the puzzle raised by den Haan et al. (2007). In particular, commercial and industrial loans show significant decline following monetary contraction when risk and balance sheet factors are accounted for, what is consistent with the predictions of the bank lending channel of monetary transmission mechanism. Robustness checks confirm that this result holds for various proxies of uncertainty – volatility measures (VIX/VXO index that captures the stock market option-based implied volatility, conditional and unconditional heteroskedasticities of GDP growth) and those that aim to measure uncertainty as vagueness (news-based uncertainty index and composite index of economic policy uncertainty). Hence, I conclude that banks play the role in the monetary transmission mechanism in line with the bank lending channel; the supply of business loans goes down after monetary tightening in addition to reduction of the supply of consumer loans and mortgages.

Next, I demonstrate that analyzing the dynamic properties of disaggregated loans gains valuable insights into the portfolio behaviour of banks. This is due to the fact that, as I show, micro components of total loans have different laws of motion. Hence, examination of disaggregated loans is beneficial comparing to the analysis of exclusively total loans' dynamics, first, for better understanding the workings of monetary transmission mechanism, and second, for understanding the regularities of various classes of loans' issuance. I show that

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<sup>5</sup>The periods I look at are 1954Q4-1979Q4 (before the turn of the US monetary policy to an anti-inflation stance in 1980-1982), 1983Q1-2007Q4 (before the financial crisis of 2007-2009) and over 2010Q2-2015Q4 (after the financial crisis).

responses of different types of loans to macroeconomic, risk and balance sheet shocks are heterogeneous. First, uncertainty shock has a negative impact on issuance of mortgages and business loans, while the effect on the volume of consumer loans issued is of the opposite sign – they go up on the impact of uncertainty shock. Second, a positive innovation to the corporate sector indebtedness reduces the issuance of business and real estate loans, while the issuance of consumer loans increases. Third, issuance of business loans and consumer loans goes down following a positive innovation to credit risk, while issuance of mortgages does not react to it significantly. Forth, a balance sheet shock, i.e. a positive innovation to banks' capital ratio, has a positive impact on business loans and consumer loans, whereas real estate loans decrease.

Forecast error variance decomposition suggests that distinct factors contribute to explaining the variance of different classes of loans: while changes in variance of commercial and industrial loans' are largely explained by changes in credit risk, variance of mortgages' volumes is mainly driven by uncertainty and balance sheet shocks; finally, consumer loans variance is explained by innovations to real activity and inflation. Uncertainty shock is the main driver of the safe assets' movements as suggested by the results of forecast error variance decomposition analysis.

Finally, I obtain evidence on substitution between different types of assets in banks' portfolios. First, banks reallocate their portfolios by reducing business loans issuance and increasing cash and securities holdings responding to uncertainty and credit risk shocks. This result pertains to business loans and safe assets as measured by their respective volumes and by shares of asset portfolio. Importantly, the robustness to distinct uncertainty measures is checked. I consider measures of macroeconomic uncertainty - news-based uncertainty index, composite policy uncertainty index, forecasters' disagreement about future inflation, VIX/VXO index and conditional and unconditional heteroscedasticity of GDP growth, together with the measures of microeconomic uncertainty - cross-sectional standard deviation of firms' pretax profit growth and cross-sectional spread of stock returns. This obtained evidence of asset portfolio reallocation from business loans to safe assets is in line with predictions of portfolio theory that states that higher riskiness of loans results in decreasing proportion of loans in portfolios. Second, I obtain the result that a positive shock to real activity induces banks to reallocate assets from cash and securities into credit. Third, a positive innovation to the indebtedness of the corporate sector entails decreasing issuance of business loans and mortgages and increasing lending to households.

My work is related to several strands of literature. First, this is the literature that investigates the empirical relevance of the bank lending channel of monetary policy, particularly, the effect of monetary policy shocks on bank lending volumes. Bernanke and Blinder (1992) demonstrate that the fall in banks' assets following monetary contraction is first concentrated almost entirely in securities; total loans feature a brief positive response in the beginning and then go down persistently. Gertler and Gilchrist (1993) and den Haan et al. (2007) look at disaggregated loans in the VAR setup and find that while real estate and consumer loans decline substantially after monetary tightening, business loans respond to an innovation to

the federal funds rate positively. To support the existence and the importance of the bank lending channel, Kashyap and Stein (1995) show the contrast in dynamics of loans issued by small and large banks; they demonstrate that large banks increase total and C&I loans after monetary contraction in two out of four of their model specifications, however, this result is statistically insignificant. Ben Mohamed (2015) uses data from the Senior Loan Officer Opinion Survey to separate out the impact of monetary easing on credit demand and credit supply, while the volume of loans issued is not taken into account, and finds that the impact of monetary easing is on business loans issuance is positive. My work differs from these studies, first, by establishing and taking into account the dates of structural changes in relationship between loans and their potential determinants; second, I control for risk and balance sheet factors in the models, whereas aforementioned works only take into account standard monetary model variables: a real activity measure, inflation and a monetary policy measure. Thereby the critical difference between the results of the previously mentioned studies and the results obtained in this chapter emerges.

Second, our paper is related to empirical literature that aims at detecting the factors fundamental for bank loans issuance. Kishan and Opiela (2000) and Van den Heuvel (2002) show that low capital levels restrain lending after monetary policy tightening. Contrary to this, Berrospide and Edge (2010) find only small effects of bank capital on lending. That banks reduce volumes of lending primarily when they face liquidity constraints is shown by Kashyap and Stein (1995) for the US, and by Angeloni, Kashyap and Mojon (2003) for the European economies. Lown and Morgan (2006) emphasize that credit standards are crucial in explaining the dynamics of business loans. Gambacorta and Marques-Ibanez (2011) demonstrate that banks' stability, in particular, banks' capital, their dependence on market funding and on non-interest sources of income play an important role as a factor of bank lending both in Europe and in the US. A growing stream of literature analyzes the effects of uncertainty on credit market developments. Stock and Watson (2012) show that shocks associated with uncertainty and financial disruptions are critical, in particular, because their influence has brought about the recession of 2007-2009. Balke and Zeng (2013) and Caldara et al. (2013) argue in favour of output and uncertainty shocks as the main drivers of financial intermediation activity. Baum et al. (2009) and Quagliariello (2008) demonstrate that macroeconomic uncertainty is a significant determinant of banks' investment decisions by presenting evidence of negative association between macroeconomic uncertainty and cross-sectional variability of banks' total loan-to-asset ratios. To the best of our knowledge, the impact of uncertainty shock on different loan components has not been studied before; this is how our work adds to existing literature.

Third, my work is related to the literature on bank risk management and portfolio allocation. Salas and Saurina (2002) demonstrate that during economic booms banks expand their lending activity and relax their selection criteria, such that in the following downturns bad loans increase, producing losses. Froot et al. (1993) and Froot and Stein (1998) use theoretical analysis to demonstrate that active risk management allows banks to hold less capital and to invest more aggressively in risky and illiquid loans. Cebenoyan and Strahan (2004) confirm

this empirically with respect to credit risk management, while Brewer et al. (2000) suggest evidence that active management of market risk influences bank performance and risk. I demonstrate that there is portfolio reallocation not only between risky loans and safe assets, but also between different classes of loans in response to macroeconomic, risk and balance sheet shocks.

## 1.2 Empirical approach

Aiming at establishing the important determinants of loan components' dynamics and at resolving the puzzle raised by den Haan et al. (2007), I start the analysis with the structural vector autoregression model as specified by den Haan et al. (ibid.), who examine the portfolio behaviour of bank loans following monetary and non-monetary shocks. The baseline VAR models include one of loans components or safe assets in addition to the federal funds rate, a price index and a real activity measure. On the next step, I extend a set of model's variables to verify, whether there is an additional information content in the other factors' variation for explaining various loans' and safe assets' dynamics. In particular, I control for corporate leverage, charge-off rate, capital ratio and uncertainty in the extended model setup.

### 1.2.1 Data

The dataset includes US quarterly data from 1954Q4 to 2015Q4. To estimate the models over the period after the 2007-2009 financial crisis break point, I use monthly data spanning from 2010M4 to 2015M12. The details of definitions, treatment and sources of the data are reported in the Appendix. Most of the data series are taken from the St Louis Federal Reserve Economic Data and the Board of the Governors of the Federal Reserve System, Data Download Program. All the monetary values are real and deflated with a GDP implicit price deflator. All the series are seasonally adjusted: they either come as seasonally adjusted by the source agency or are adjusted with the X-13ARIMA-SEATS algorithm. Additionally, the variables' values are taken in logs (with the exception of interest rates). Figure 1.1 in Appendix shows the levels data for the variables.

We use bank loan series from the H.8 releases (Asset and Liabilities of Commercial Banks in the United States) by the Federal Reserve. I analyze data on banks' commercial and industrial loans<sup>6</sup>, real estate loans, consumer loans<sup>7</sup> and safe assets. Safe assets include cash and Treasury and agency securities, i.e. assets with low/minimal level of risk. These four types of assets comprise 66-79% of commercial banks' total assets depending on the period<sup>8</sup>.

<sup>6</sup>I use "commercial and industrial loans" and "business loans" interchangeably.

<sup>7</sup>There is an upward spike in the volume of all types of loans (especially, in consumer loans) in the beginning of 2010 due to a new reporting requirement issued by the Financial Accounting Standards Board. To avoid including this spike into the model, I estimate the model after the financial crisis period on the sample that starts in 2010Q2 (or 2010M4).

<sup>8</sup>The types of bank assets, which are not analyzed here, are interbank loans, loans to commercial banks, trading assets, other securities, other loans and leases and other assets.



The percentages of each class of asset in total portfolio are reported in Table 1.4 in Appendix. Figure 1.3 displays their dynamics.

Federal funds rate is taken as a benchmark measure of monetary policy, given that it records shocks to supply of bank reserves and is a good indicator of monetary policy actions<sup>9</sup>. I employ three-month rate on Treasury bills and nonborrowed reserves of depository institutions as alternative monetary policy measures for robustness check of monetary policy effects<sup>10</sup>.

Leverage is a measure of the corporate sector indebtedness, which could potentially be an important determinant of business loans' issuance. Recent evidence shows that leverage is a key factor shaping financial vulnerability<sup>11</sup>, that's why I look at it as at a measure of ex-ante riskiness of non-financial corporates. Credit risk of a particular class of bank loans, i.e. ex-post riskiness of loans, is measured by a charge-off rate on loans.

### 1.2.2 Uncertainty measures

I use two types of uncertainty measures for the purposes of the current analysis: measures of macroeconomic and microeconomic uncertainty. Two groups of proxies are employed to measure macroeconomic uncertainty: volatility measures and measures that capture uncertainty as "vagueness". Among the former, the first one is a realized unconditional volatility of GDP growth based on rolling sample standard deviations over a 5 years window<sup>12</sup>:

$$\sigma_t = \left( \sum_{j=1}^{20} g_{t+j}^2 - \frac{1}{20} \sum_{j=1}^{20} g_{t+j} \right)^{1/2}, \quad (1.1)$$

where  $g_i$  is an annualized quarter-to-quarter growth rate of real GDP.

Second, I use conditional volatility of GDP growth to measure uncertainty. I estimate heteroscedasticity of real GDP growth with GARCH (1,1)<sup>13</sup>. In particular, the volatility is estimated as a conditional variance from GARCH model. The mean equation of GARCH specification is:

$$g_t = c + \theta g_{t-1} + \varepsilon_t, \quad (1.2)$$

where  $c$  and  $\theta$  are parameters, and  $\varepsilon_t$  is a heteroscedastic error term. The conditional variance equation is:

$$\sigma_t^2 = \omega + \alpha \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2, \quad (1.3)$$

where the conditional variance  $\sigma_t^2$  is specified using parameters  $\omega$ ,  $\alpha$  and  $\beta$ , news about

<sup>9</sup>I go along McCallum (1983), Bernanke and Blinder (1992), Bernanke and Mihov (1998) and Sims (1992) in that.

<sup>10</sup>Eichenbaum (1992) and Christiano and Eichenbaum (1992) argue that innovations to nonborrowed reserves primarily reflect exogenous shocks to monetary policy, while innovations to broader monetary aggregates primarily reflect shocks to money demand.

<sup>11</sup>See, for example, Shularick and Taylor (2012) and Gourinchas and Obstfeld (2012).

<sup>12</sup>Unconditional volatility of GDP growth is used a macroeconomic uncertainty measure, for example, in Fogli and Perri (2015) and in Basu and Bundick (2015).

<sup>13</sup>A similar measure of macroeconomic uncertainty was constructed in Cesa-Bianchi and Fernandez-Corugedo (2014) on TFP data.

volatility from the pervious period  $\varepsilon_{t-1}^2$  and last period's forecast variance  $\sigma_{t-1}^2$ . The results of GARCH (1,1) model estimation are given in Table 1.7.

The last measure of uncertainty as volatility used here is VXO index, a stock market option-based implied volatility proxy, which measures anticipated volatility of the Standard & Poor's 100 index. Instead of using data on conventional VIX index, which measures expected volatility of the S&P 500 index, I use data on VXO index, because data for the latter index is available for the longer time period - starting from 1986, - comparing to data available for VIX index - starting from 1990<sup>14</sup>. Both VIX and VXO indices are used as measures of short-term macroeconomic uncertainty, as they represent the expectations of the market about its volatility in the next 30 days. VIX has been previously used as a proxy for uncertainty at the firm level, for instance, in Leahy and Whited (1996) and in Bloom et al. (2007).

The second group of macroeconomic uncertainty measures are those that aim to capture vagueness or 'unknownness' of future economic outlook. I employ the news-based economic uncertainty index, the composite index of economic policy uncertainty index, constructed by Baker et al. (2016) and forecasters' disagreement about future inflation. The forecasters' disagreement about future inflation measures the dispersion between individual forecasters' predictions about future levels of the Consumer Price Index and is used with data coming from the Federal Reserve Bank of Philadelphia's Survey of Professional Forecasters. News-based uncertainty index quantifies newspaper coverage of economic uncertainty, related to policy. In particular, it is the index of search results from 10 large newspapers, from which a normalized index of the volume of news articles discussing economic policy uncertainty is constructed<sup>15</sup>. The composite economic policy uncertainty index developed in Baker et al. (2016) captures the compound effect on policy uncertainty of several factors, including, first, the news-based uncertainty, second, uncertainty about the future path of the federal tax code, and third, disagreement of professional forecasters about government spending and inflation.

The measures of microeconomic uncertainty used in the current analysis are cross-sectional standard deviation of firms' profit growth and cross-firm stock return variation. The former one measures the within-quarter cross-sectional spread of pretax profit growth rates normalized by average sales. As suggested by Bloom (2009), profit growth has a close fit to productivity and demand growth in homogenous revenue functions, and hence, its standard deviation across firms could be used as a pertinent proxy for idiosyncratic or microeconomic uncertainty. The latter microeconomic uncertainty measure, suggested in Bloom et al. (2016), is an interquartile range of firms' monthly stock returns. This uncertainty proxy discloses how volatile are perceptions of the stock market participants about firms' performance. Campbell et al. (2001) demonstrate that in booms cross-sectional spread of stock returns is about 50% lower than in recessions; Bloom et al. (2016) also show that this uncertainty measure is countercyclical.

Table 1.1 shows that pairwise correlations between various uncertainty measures range

<sup>14</sup>See <http://www.cboe.com/micro/vix-options-and-futures.aspx> for details.

<sup>15</sup>See <http://www.policyuncertainty.com> for details.

Table 1.1: Pairwise correlation coefficients between uncertainty measures

	UV GDPg	CV GDPg	VXO	NB UI	P UI	FD	SD pr g	CF SRV
Unconditional volatility of GDP growth	1***							
Conditional volatility of GDP growth	0.75***	1***						
VXO	0.15*	0.41***	1***					
News-based uncertainty index	0.40***	0.38***	0.53***	1***				
Policy uncertainty index	0.63***	0.47***	0.41***	0.88***	1***			
Forecasters' disagreement	0.53***	0.31**	0.24***	0.14*	0.49***	1***		
Standard deviation of firms' profit growth	0.13	0.33**	0.41**	0.18**	0.09	-0.02	1***	
Cross-firm stock return variation	0.11	0.51***	0.75***	0.53***	0.43***	0.14*	0.29**	1***

Note. \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ . The following abbreviations are used: UV GDPs - unconditional volatility of GDP growth, CV GDPg - conditional volatility of GDP growth, VXO - VXO index, NB UI - News-based uncertainty index, P UI - Policy uncertainty index, FD - forecasters' disagreement about future inflation, SD pr g - standard deviation of firms' pretax profit growth, CF SRV - cross-firm stock return variation. The sample is 1954Q4-2015Q4 or the longest one over this period, for which the data is available.

from very low and insignificant (for example, between cross-firm stock return variation and unconditional volatility of GDP growth) to high and significant (for example, between VXO index and cross-firm stock return variation), Figure 1.2 plots series for the uncertainty measures discussed here. Composite policy uncertainty index and news-based uncertainty index co-move together (correlation coefficient 0.88), because the latter one is one of the components of the former. High correlation is also observed between conditional and unconditional volatility of GDP growth (0.75). Generally, microeconomic uncertainty measures tend to be correlated with macroeconomic ones to the less extent than macroeconomic uncertainty proxies between each other. In particular, this refers to standard deviation of pretax profit growth that shows only weak or moderate correlation with other uncertainty measures. Hence, there are significant differences between dynamic properties of distinct measures of uncertainty.

### 1.2.3 Empirical methodology

I follow a conventional procedure to study the impact of monetary policy and other non-monetary factors on bank loan variables and estimate a structural vector autoregression model. A model considered is:

$$Z_t = B_1 Z_{t-1} + \dots + B_q Z_{t-q} + u_t, \quad (1.4)$$

where  $Z_t$  is a  $k$ -dimensional vector of observable variables,  $u_t$  is a  $k$ -dimensional vector of reduced-form error terms, and consistent estimates of the coefficients  $B_i$ 's are obtained by running ordinary least squares equation by equation on (1.4).  $Z_t$  is partitioned into the blocks:

$$Z_t = \begin{pmatrix} X_{1t} \\ S_t \\ X_{2t} \end{pmatrix},$$

where  $S_t$  is a monetary policy instrument, the federal funds rate, or alternatively, the volume of nonborrowed reserves of depository institutions, or a three-month rate on Treasury bills.  $X_{1t}$  is a  $(k_1 \times 1)$  vector with elements whose contemporaneous values are in the information set of the central bank, such that  $S_t$  is affected by variables in  $X_{1t}$  contemporaneously;  $X_{1t}$  is not influenced by  $S_t$  in period  $t$ .  $X_{2t}$  is a  $(k_2 \times 1)$  vector with elements whose contemporaneous values are not in the information set of the central bank, so  $S_t$  is not affected by their influence, but it does exert an impact on them in period  $t$ .  $k = k_1 + 1 + k_2$ . Drawing from Christiano et al. (1999), I assume that the relationship between the VAR disturbances and the fundamental economic shocks,  $\varepsilon_t$ , is given by

$$u_t = \tilde{A}\varepsilon_t. \quad (1.5)$$

$\tilde{A}$  is a  $(k \times k)$  matrix of coefficients, and  $\varepsilon_t$  is a  $(k \times 1)$  vector of uncorrelated fundamental shocks with a unit standard deviation each, so  $E[u_t u_t'] = \tilde{A} \tilde{A}'$ . To determine the effects of a monetary policy shock, a restriction, imposed on  $\tilde{A}$ , is that it is a block lower-triangular matrix:

$$\tilde{A} = \begin{bmatrix} \tilde{A}_{11} & 0_{k_1 \times 1} & 0_{k_1 \times k_2} \\ \tilde{A}_{21} & \tilde{A}_{22} & 0_{1 \times k_2} \\ \tilde{A}_{31} & \tilde{A}_{32} & \tilde{A}_{33} \end{bmatrix},$$

where  $\tilde{A}_{11}$  is a  $(k_1 \times k_1)$  matrix,  $\tilde{A}_{21}$  is a  $(1 \times k_1)$  matrix,  $\tilde{A}_{31}$  is a  $(k_2 \times k_1)$  matrix,  $\tilde{A}_{22}$  is a  $(1 \times 1)$  matrix,  $\tilde{A}_{32}$  is a  $(k_2 \times 1)$  matrix,  $\tilde{A}_{33}$  is a  $(k_2 \times k_2)$  matrix, and  $0_{i \times j}$  is a  $(i \times j)$  matrix with zero elements.

For the benchmark specification I assume that  $X_{2t}$  is empty. In particular, the assumption is that monetary authority observes and responds to contemporaneous information on all other variables. I consider this is a plausible assumption given that data on price level, industrial output, aggregate employment and other indicators of aggregate real economic activity are available to the FED on monthly basis<sup>16</sup>. I find empirical support for this assumption: a pairwise Granger causality test suggests that the direction of Granger-causation runs from loans to funds rate and not the other way around (Table 1.6). In the New Keynesian approach this assumption corresponds to the notion of a feedback interest rate rule of

<sup>16</sup>This assumption is made, among others, by Christiano and Eichenbaum (1992), Christiano et al. (1999), Eichenbaum and Evans (1995), Strongin (1995), Bernanke and Blinder (1992), Bernanke and Mihov (1995), and Gertler and Gilchrist (1994).

monetary authority, which closes general equilibrium models. For robustness check I also consider an alternative order:  $X_{1t}$  is assumed to be empty. This alternative identification scheme is adopted by den Haan et al. (2007), who assume that monetary authority does not respond to contemporaneous information.

We place loan volumes on the last place in  $X_{1t}$  block. The assumption is that banks observe contemporaneous information on real activity and inflation when deciding on loans' issuance. Cross-correlation coefficients between growth of loans and GDP growth, on one side, and between growth of loan and inflation, on the other side, indicate that GDP and inflation lead loan volumes. Granger causality tests show that past values of GDP help to predict loans and not the other way around. This evidence justifies making the assumption of bank loans being ordered after a real activity and inflation measures. I also try an alternative order when loan volumes are placed after the federal funds rate, based on the assumption that banks see the policy rate set by the central bank contemporaneously, in this case all the variables are placed in block  $X_{2t}$ , while  $X_{1t}$  is empty.

Thus, the variables' order in the baseline model is: a real activity, an inflation measure, loan volumes or safe assets (added one at a time) and a monetary policy instrument. An alternative order that I use for robustness check of monetary policy effects is: a monetary policy instrument, a real activity measure, inflation proxy and a loan volumes or safe assets component.

A wider set of variables is included in the extended model. In particular, measures of uncertainty, capital ratio, charge-off rates and leverage of non-financial corporate sector are used to assess whether there is an additional information content in fluctuations of these factors for explaining variations of bank loans and safe assets. This ordering is based on several assumptions. First, it is assumed that uncertainty shocks influence all other variables contemporaneously, such that uncertainty is an underlying characteristic of the state of economy being unaffected by other variables contemporaneously, i.e. within the same quarter<sup>17</sup>. This consideration is corroborated by estimates of cross-correlation between uncertainty proxies and business loans – the former leading the latter (Table 1.5), - and by Granger causality tests, which show that when Granger causality effect is significant, the direction of this effect goes from uncertainty to loans (Table 1.6)<sup>18</sup>. It is worth noticing that the strongest negative correlation between uncertainty and business loans is found for the following uncertainty proxies: VXO index, news-based uncertainty index and composite policy uncertainty index. Granger causality tests confirm tight relation of loans to VXO index and news-based index, for which the Granger causation effects are significant. I use news-based uncertainty as a benchmark measure of economic uncertainty in our extended model. The results for employing alternative uncertainty measures are available in the Appendix.

Leverage of non-financial corporates is placed after the real activity and inflation mea-

<sup>17</sup>The same identification scheme is employed by Bachmann et al. (2012) and by Bonciani and van Roye (2016), where the uncertainty measure is ordered first in the VAR.

<sup>18</sup>This holds for all uncertainty proxies except for conditional volatility of GDP growth, for which correlation with loans is found to be nonsignificant and Granger causality effect doesn't go in the direction from uncertainty to loans.

Table 1.2: VAR models under consideration.

	Baseline model	Extended model
Variables (in the VAR order)	Real GDP GDP deflator Loans/safe assets' component Federal funds rate (or an alternative policy measure) <i>For robustness check of monetary policy effects</i> Federal funds rate (or an alternative policy measure) GDP Inflation Loans/safe assets' component	Uncertainty measure Real GDP GDP deflator Leverage of corporates Capital ratio Loans/safe assets' component Charge-off rate Federal funds rate <i>For robustness check of uncertainty shocks effects</i> Real GDP GDP deflator Leverage of corporates Capital ratio Loans/safe assets' component Charge-off rate Federal funds rate Uncertainty measure
Estimation periods	1) 1954Q4-1979Q4 (quarterly data) 2) 1983Q1-2007Q4 (quarterly data) 3) 2010M4-2015M12 (monthly data)	1985Q1-2007Q4 (quarterly data)

Note. For the baseline model the last estimation period starts in 2010M4 and not earlier, because the data on loans has a break in March and April of 2010, when the new reporting requirements issued by the Financial Accounting Standards Board were introduced. Financial Accounting Statements (FAS) 166 and 167 have implications for how banks treat off-balance-sheet special purpose vehicles.

asures based on the assumption that companies observe contemporaneous values of uncertainty, real activity and inflation, when making decision about how much debt to incur, whereas all credit variables are not observed by them. Capital ratio of banks is placed before loans. Capital adequacy requirements affect the amount of risky assets banks can have on their balance sheets, and that is the reason why I assume that banks see and take into account the level of their capital ratio when making decisions about risky loans' issuance. Asset component variable (safe assets or loans) is placed after the capital ratio. The assumption is that banks observe contemporaneous information on uncertainty, real activity, inflation, indebtedness of corporates and capital ratio, when deciding on loans' issuance and how much safe assets to hold. Charge-off rate on loans is placed after loan volumes. It is assumed that the value of loans removed from the books and charged against loss reserves is affected by the

volume of loans issued by banks to firms contemporaneously. Thus, the variables' order in the extended model is: an uncertainty proxy, a real activity measure, an inflation measure, leverage of the corporates, banks' capital ratio, loan volumes or safe assets (added one at a time), charge-off rate on a certain class of loans (or a charge-off rate on total loans in case of a VAR with total loans or safe assets) and a monetary policy instrument.

Based on Akaike information criterion (AIC) and in line with Schwarz and Hannan-Quinn information criteria, the benchmark specification of the model includes two lags. The lag orders of the extended model specifications are also based on AIC and are given in notes to respective figures in Appendix.

### 1.3 Stability analysis

Empirical business cycles literature argues that there have been important changes in the characteristics of dynamics of the series analyzed<sup>19</sup>: a shift of the US monetary policy to an anti-inflation stance in 1980-1982 and the financial crisis of 2008-2009. I employ formal structural stability tests to check our VAR models for the parameters' stability at these two possible break dates.

We use Chow tests to test the hypothesis of VAR models parameters' constancy following Canova (2007) and Lutkepohl (2005). The null hypothesis of time invariance of the parameters throughout the sample period is checked against the possibility of a change in the parameter values at period  $T_B$ . I consider three versions of Chow tests: break-point test, sample-split test and Chow forecast test<sup>20</sup>. P-values are computed in two ways: first, treating the break date as unknown (this serves the purpose of detecting the date of structural break), and second, treating the break date as determined exogenously (to confirm the break existence, or as a robustness check of the result obtained at the first step). See section 1.6.2 in Appendix for details of the approach used.

The Chow tests are designed to detect one potential structural break from the sample<sup>21</sup>. Our sample period 1954-2015 includes two possible shifts, therefore, I apply the tests for two adjacent time intervals separated by one potential break date and exclude the interval left. Hence, testing for parameters stability during the US monetary policy shift, I exclude the period from the onset of financial crisis from the test. The test sample in this case is 1954Q4 to 2007Q4. Testing the hypothesis of model's parameters stability during the financial crisis I exclude the period before 1980. The test sample in this case is 1983Q1 to 2015Q3. Results of testing for structural breaks are given in Table 1.3.

All the versions of the Chow test statistics reject the null hypothesis of parameters stability in the VAR models over the analyzed sample period. I conclude that there are structural changes in the models' parameters in 1980-1982 and in 2007-2009. Therefore, the first period that I estimate our vector autoregressive models for is 1954Q1-1979Q4, the second one

<sup>19</sup>See Bernanke and Mihov (1998), Cogley and Sargent (2002), Primiceri (2006), Stock and Watson (2003) and Koop et al. (2009), among others.

<sup>20</sup>See Lutkepohl et al. (2006), Candelon and Lutkepohl (2001) and Hendry and Doornik (1997) for details.

<sup>21</sup>See Canova (2007) and Lutkepohl (2001) for details on this.

Table 1.3: The results of the Chow tests for structural changes

	Test sample period	Unknown break date test		Exogenously determined break date		
		Supposed break-point interval	The identified break date	Chow break-point test	Chow split-sample test	Chow forecast test
				$\lambda_{BP}$	$\lambda_{SS}$	CF
The US monetary policy shift	[1954Q4, 2007Q4]	[1979Q1, 1983Q4]	1980Q4	240.541***	165.928***	8.581***
The financial crisis 2008-2009	[1983Q1, 2014Q4]	[2008Q1, 2009Q4]	2008Q3	147.675***	90.707***	1.749***

Notes. The main entries are tests statistics for Chow tests to check the null hypothesis that the set of VAR(2) model parameters is constant: for the US monetary policy shift - over the period from 1954Q4 to 2007Q4, and for the financial crisis 2007-2009 – over the period from 1983Q1 to 2015Q3. \*\*\*  $p < 0.01$ . For robustness checks I perform the tests for VAR models with different lag orders. These tests also reject the null hypothesis of the models' parameters stability.

- 1983Q1-2007Q4 and the third one - 2010M4-2015M12. Monthly data is used to analyze the dynamics of loans after the financial crisis due to lack of quarterly observations. Given that 1980-1982 and 2007-2009 are the periods of extreme volatility associated with unprecedented monetary policy measures (monetary base control), I exclude them from the study, due to their dynamic characteristics being not indicative for the rest of the sample. I start the third sample in 2010M4 and not earlier, because the data on loans has a break in March and April of 2010, when the new reporting requirement issued by the Financial Accounting Standards Board were introduced<sup>22</sup>.

## 1.4 Estimation results and robustness

### 1.4.1 Baseline model

I begin by analyzing the results of the baseline model. It includes a real activity measure, a measure of inflation, loan component (one of the loan classes or safe assets included in the VAR one at a time) and the federal funds rate. Though my VAR specification draws from den Haan et al. (2007), there are some differences with their analysis. First, I estimate the model over several periods taking into account structural breaks dates; second, I increase the size

<sup>22</sup>Financial Accounting Statements (FAS) 166 and 167 have implications for how banks treat off-balance-sheet special purpose vehicles.



of the sample<sup>23</sup>; third, I perform robustness check of monetary policy shock effects by using alternative policy indicators; and forth, I analyze responses of safe assets and total loans to monetary and real activity shocks, what is not done in den Haan et al. I analyze the results in form of impulse responses and forecast error variance decomposition of disaggregated and total loans and safe assets. 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998).

Figures 1.4-1.8 in the the chapter appendix plot the responses of business loans, real estate loans, consumer loans<sup>24</sup>, total loans and Treasury and agency securities after one-standard deviation shocks to the federal funds rate, real activity and inflation under the benchmark specification of the VAR, i.e. when the federal funds rate is placed last in the VAR. Figures 1.9-1.13 in this chapter appendix plot impulse responses under the alternative specification of the model, i.e. when the federal funds rate is placed first in the VAR. Figures 6-10 in Appendix D<sup>25</sup> plot impulse responses for the model with an alternative measure of monetary policy – 3-month Treasury bill rate that is placed the last in the VAR according to our baseline model specification. Finally, figures 11-15 in Appendix D plot impulse responses for the model with an alternative measure of monetary policy – nonborrowed reserves of depository institutions that are placed the last in the VAR<sup>26</sup>.

There are significant differences between responses of loans to shocks over different periods. I obtain that significant positive impact of monetary policy contraction on business loans - the effect found in den Haan et al. (2007) - is characteristic for this class of loans only for the period 1983Q1-2007Q4 (Figure 1B, the chapter appendix). Over the periods 1954Q4-1979Q4 and 2010M4-2015M12 a significant negative effect of monetary tightening on business loans is observed (Figures 1A and 1C in the chapter appendix). The alternation of negative and positive effects of monetary policy shocks from one time period to another is obtained in the benchmark and alternative baseline model specifications (Figures 1.9, the chapter appendix). Robustness checks show that when 3-month Treasury bill rate is used as a monetary policy measure, business loans' increase after monetary tightening significantly (Figure 6B, Appendix D), whereas when nonborrowed reserves measure monetary policy actions, this effect is positive but nonsignificant (Figure 11B, Appendix D).

The other classes of loans - real estate loans and consumer loans - decrease responding to monetary contraction in all the time period subsamples, what is consistent to bank lending channel of monetary policy transmission mechanism (Figures 1.2 and 1.3, the chapter appendix). I demonstrate that the size of these negative response gets smaller with time: over

<sup>23</sup>The sample in den Haan et al. (2007) spans from 1977Q1 to 2004Q2.

<sup>24</sup>Due to an upward spike in consumer loans in the beginning of 2010, because new reporting requirement issued by the Financial Accounting Standards Board, were set in place, I estimate the VAR with the consumer loans until 2009Q4.

<sup>25</sup>Appendix D contains the set of plots providing the complete results of robustness tests. I don't include them in the main body of thesis due to the large volume. Appendix D is available from the author upon request.

<sup>26</sup>I estimate the latter version of the model for all the sub-samples (1954Q4-1979Q4, 1983Q1-2007Q4, and 2010M4-2015M12), even though the values of nonborrowed reserves of depository institutions underwent substantial changes in 2008 that are not generally characteristic to the dynamics of this series (For more details, see Statistical Releases from the Federal Reserve: <http://www.federalreserve.gov/feeds/h3.html>), because the break date in 2008 is not included in any of the sub-sample periods.

1954-1979 one standard deviation shock to monetary policy reduces mortgages by 1.65% and consumer loans by 1.84%; over 1983-2007 – by 0.49% and 0.41%, over 2010-2015 – by 0.24% and 0.06% respectively. These findings are robust to VAR specification and to the measure of monetary policy used (Figures 2, 3, 7, 8, 12, 13, Appendix D). In addition to negative effects, I find that consumer and real estate loans feature brief and mostly insignificant positive responses to monetary contraction (Figures 2B, 2C, 3B in the chapter appendix), which are also present in den Haan et al. (2007).

Next, I observe that over 1983-2007 total loans go up following monetary contraction, while in subsamples 1954-1979 and 2010-2015 they are reduced after a positive shock to the federal funds rate. This dynamics reflects the patterns of loan components (Figures 4A, 4B, 4C in the chapter appendix), specifically, of business loans positive response to monetary contraction. This finding, which is robust to specification of VAR and to the measure of the monetary policy used, differs from the results shown in Gertler and Gilchrist (1993) and in den Haan et al. (2005), where they document the estimated response for total loans as not robust and not significant. However, this finding is in line with the results of Kashyap and Stein (1995), who also demonstrate that total loans go up after monetary tightening in some of their specifications. I conjecture that this difference emerges, because structural breaks are not taken into account in Gertler and Gilchrist (1993) and in den Haan et al. (2005)<sup>27</sup>. As a result, the negative effect of monetary tightening on total loans that I find for the period before 1980's gets mixed with the positive impact of total loans to contraction that I find for the period after 1980's, so that the resulting effect is not robust and insignificant. Still, I show that this positive reaction of total loans dies out after 6 quarters from the shock impact, when total loans go down following monetary tightening over all time period samples.

All classes of loans go up following a positive innovation to real economic activity, while Treasury and agency securities holdings are reduced (Figures 5A, 5B, 5C, the chapter appendix). This reveals banks' preference to substitute out safe assets with risky loans on their balance sheets in the times of better economic conditions. Specifically, banks' assets portfolios are reallocated in response to a positive real activity shock in the way that makes portfolios riskier. This finding is significant and valid for all the time period subsamples analyzed.

We conjecture that puzzling positive response of commercial and industrial loans to monetary contraction in 1983-2007 might be the case of omitted variable bias, i.e. inability of a small monetary policy VAR to capture the critical forces that drive business loans volumes. I extend the set of model's variables to test this hypothesis.

### 1.4.2 Extended model

In this section I report the results of the extended model estimation over the period 1983-2007, which is completed to improve understanding of the workings of monetary transmission mechanism on commercial and industrial loans. I aim to resolve the puzzling response

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<sup>27</sup>The samples analyzed at in den Haan et al. (2005) are 1960-2003 for H8 data and 1977-2000 for Call Report Data.

of this class of loans to monetary contraction over 1983-2007 obtained with the baseline model. I augment the model with a set of risk and balance sheet variables: macroeconomic uncertainty, portfolio credit risk (measured by charge-off rate on respective class of loans), leverage of corporates, and banks' capital ratio, measured as a ratio of banks' equity capital to total assets. In the benchmark version of the extended model the news-based uncertainty index is used as uncertainty measure. The results in form of impulse responses and forecast error variance decomposition for extended model are given on Figures 1.14-1.20 and Tables 1.8-1.12 in the the chapter appendix; the results of employing alternative uncertainty measures are available on Figures 16-28 in Appendix D.

The counterintuitive positive response of commercial and industrial loans to monetary tightening, observed in the case of the baseline model, is not present, when risk and balance sheet factors are controlled for. Specifically, positive innovation to federal funds rate exerts a significant negative effect on business loans in the extended model version (Figure 1.14A, the chapter appendix). Robustness checks are performed with all the measures of macroeconomic uncertainty discussed above, and they confirm this finding (Figures 16-18, Appendix D). Real estate and consumer loans go down upon monetary contraction in the way they do in the baseline model version (Figures 1.14A, 1.15A, Appendix C).

We therefore conjecture that the positive effect of monetary tightening on business loans in the baseline model is the case of omitted variable bias, when the effects of important loan volumes' determinants are left out. All of the variables added to the extended model – macroeconomic uncertainty, corporate leverage, portfolio credit risk and banks' capital ratio – are correlated with business loans volumes significantly and feature significant Granger causality relationships with them (Tables 1.5 and 1.6 in the chapter appendix). Forecast error variance decomposition analysis reveals that a shock to portfolio credit risk contributes up to 24% of business loans' variability, making it the most important determinant of business loans' volumes dynamics (Table 1.8 in the chapter appendix). I conclude that portfolio credit risk is a critical factor that should be accounted by a model that aims at explaining loan volumes' movements. I conjecture that the baseline model features a counterintuitive positive response of business loans to monetary policy shock due to the absence in the baseline model of a credit risk variable, which is particularly influential for C&I loans. I obtain that monetary tightening leads to significant increases in charge-off rate on C&I loans, macroeconomic uncertainty also goes up (Figure 1.14B in the chapter appendix). Hence, higher level of credit risk and uncertainty, together with a reduced GDP, put a downward pressure on business loans issuance following monetary contraction.

Shocks to credit risk are also an important driver of consumer loans movements. Additionally, real activity shocks and innovations to inflation help to explain variance of consumer loans (Table 1.10 in the chapter appendix). In contrast to this, changes in issuance of mortgages are not driven by credit risk shocks. Cost shocks, shocks to monetary policy and to the leverage of the corporate sector contribute to explanation of the variance of real estate loans (Table 1.9 in the chapter appendix). The finding that innovations to credit risk do not explain movements of the real estate loans might contribute as an evidence to the discussion

about the causes of the subprime mortgage crisis.

The effect of a positive innovation to charge-off rates on business and consumer loans is significantly negative (Figures 1.14A and 1.17A in the chapter appendix), whereas safe assets react to this shock positively (Figure 1.19A in the chapter appendix). Hence, banks reallocate their portfolios following positive credit risk shocks by reducing loans issuance and increasing their safe assets holdings<sup>28</sup>.

The dynamic patterns of loan components to macroeconomic uncertainty shock are also heterogeneous. The impact of a positive innovation to uncertainty on business loans depends on the nature of uncertainty measure employed. A positive shock to vagueness-type measures of uncertainty, such as news-based uncertainty index or composite index of economic policy uncertainty, makes a significantly negative effect on the issuance of commercial and industrial loans (Figure 1.14A in the chapter appendix and Figure 16A, Appendix D). A shock to macroeconomic uncertainty measured as volatility of GDP growth (conditional or unconditional) also drives business loans down, but these negative impacts are statistically insignificant (Figures 16C, 16D, Appendix D). The impact of positive innovation to the stock market option-based implied volatility increases C&I loans insignificantly (Figure 16B, Appendix D). I therefore conclude that changes in innovations to volatility (of GDP growth or stock market) don't reduce business loans' issuance as much as a spike of "unknownness" of the future economic outlook does.

To find out what is the reason of this disparity in responses of business loans to different types of macroeconomic uncertainty shocks, I estimate impulse responses of the variables to innovations in uncertainty, using all the macroeconomic uncertainty proxies at hand. I obtain that there is a significant difference in responses of the leverage of the corporate sector to different types of uncertainty shocks, while all the other variables respond to distinct types of uncertainty shocks in the same way (Figures 1.14C and 1.14D in the chapter appendix). The critical disparity is that corporate sector responds to positive innovations to volatility by reducing their leverage, while innovations to uncertainty defined as vagueness/unknownness of economic outlook make firms increase their indebtedness. I conjecture that this happens, because when economic perspectives are unclear, firms don't necessarily relate the state of unknownness to only worse economic conditions in future or threats, but also foresee opportunities. Then it is important for companies to secure funding, so that benefits of improved economic conditions can be enjoyed. The fact that firms are more indebted puts downward pressure on the supply of C&I loans (indebted borrowers are more financially vulnerable) and on demand for C&I loans (indebted firms are less willing to ask for additional borrowings). Hence the significant negative response of business loans to uncertainty shock, when uncertainty is defined as vagueness/unknownness of economic outlook.

In contrast to this, an innovation to volatility measure of uncertainty leads to decrease of the leverage of non-financial corporates. I admit that this effect is present due to firms aiming at reduction of their debt in face of more volatile GDP growth and/or stock market. In

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<sup>28</sup>Real estate loans feature a brief positive response to the credit risk shock (Figure 1.16A in the chapter appendix), but this result is not robust across alternative model specifications.

case of high volatility the possibility of decreasing business returns is more evident than in the case of vague economic perspectives. Relatively low level of leverage does not depress supply and demand for loans in the contrast to the case of vagueness-type of macroeconomic uncertainty measure. Hence, there's no significant reduction of C&I loans following innovation to volatility measure of uncertainty.

As an additional robustness check and to provide an empirical evidence for the theoretical model constructed in the next chapter, where I examine the impact of idiosyncratic uncertainty on issuance of business loans and banks' safe assets, I analyze impulse responses of credit and macroeconomic variables in the extended model to microeconomic uncertainty shock. My result of the impact of microeconomic uncertainty shock on the key aggregates is in line with empirical findings present in literature<sup>29</sup>. Specifically, figure 1.15A shows that a positive shock to uncertainty induces a significant reduction of output, inflation and federal funds rate. I also find that capital ratio and charge off rate on business loans go up following a positive shock to microeconomic uncertainty. Controlling for aggregate demand, inflation, corporate sector indebtedness and capital ratio of banks, commercial and industrial loans go down following an uncertainty shock by 0.5%. Figure 1.20A demonstrates that there is a significant increase of the safe assets' holdings by banks after an exogenous spike in uncertainty - by 0.4%. Figure 1.15B shows that the result of the business loans reduction following an exogenous increase of uncertainty holds not only for the volume of loans issued, but also for the share of commercial and industrial loans in portfolios of assets of banks. The share of business loans goes down by 0.08 pp and stays reduced for a period up to 15 quarters after a positive shock to uncertainty. Figure 1.20B demonstrates that the result of the safe assets increase after an uncertainty shock is long-lasting and holds for the share of safe assets in the portfolios of banks: this share goes up by 0.1 pp with this increase being significantly positive for after 20 quarters after the impact of the shock.

Real estate loans go down after a positive innovation to uncertainty disregarding the type of the measure of uncertainty employed. Moreover, unlike the case of C&I loans, uncertainty shock (together with shock to banks' capital ratio) is one of the major determinants of mortgages volumes' variance on the horizon of 8 quarters (Table 1.9 in the chapter appendix).

Interestingly, consumer loans increase upon impact of uncertainty shock; this result is robust to various macroeconomic uncertainty proxies (Figure 1.17A in the chapter appendix and Figures 22A, 22B, Appendix D). This positive impact of uncertainty on consumer loans is a brief one, it lasts as statistically significant for 1 quarter following the shock impact. No significant negative effect of uncertainty on consumer loans is found. I conjecture this might be the case of increase in demand for consumer loans in more uncertain macroeconomic environment, when individuals choose to secure external sources of funding due to foreseen possibility of being unable to borrow more in future. I suggest that the reasons of this positive impact of uncertainty shock on consumer loans volumes need to be investigated in future research.

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<sup>29</sup>See, among others, Bloom (2009), Caldara et al. (2016), Balke and Zeng (2013), Bachmann et al. (2013), Bonciani and van Roye (2016).

Banks increase their safe assets holdings following uncertainty shocks (Figures 1.19 and 1.20 in the the chapter appendix Appendix C and Figures 26, 27, 28, Appendix D), thus reallocating assets in their portfolios by substituting risky loans with cash and securities.

A positive shock to indebtedness of corporates has heterogeneous effects on various classes of loans. While business and real estate loans go down after a shock to leverage, consumer loans show a significant positive response to positive innovation to leverage. Hence, this shock makes banks substitute loans issued to firms with loans issued to individuals due to higher financial fragility of the corporate sector characterized by their higher indebtedness. Increase of safe assets holdings in this case does not occur. Forecast error variance decomposition shows that variance of real estate loans' volumes is explained by innovations to corporates' leverage to a considerable extent: 20-29% of mortgages' variance is driven by this factor on 16-24 quarters horizon (Table 1.9 in the chapter appendix). Only 6-7% of business loans volumes variance is explained by innovations to leverage of firms (Table 1.8 in the chapter appendix), for the consumer loans volumes, 1-3% of movements are explained by the shock to firms' indebtedness. Hence, how much debt is incurred by firms relative to their assets, matters primarily for real estate loans issuance<sup>30</sup>. Interestingly, corporates' indebtedness is also a statistically significant determinant of total loans' dynamics: 21-29% of total loans' variance is explained by it on the horizon of 11-24 quarters (Table 1.11 in the chapter appendix).

The impact of positive innovations to capital ratio on various classes of loans is different as well: while the effect on business and consumer loans is positive (though statistically insignificant, see Figure 1.14A and 1.17A, Appendix C), the influence on real estate loans is statistically significant and negative (Figure 1.16A, Appendix C). The result obtained for business and consumer loans is consistent with the idea that higher bank equity allows to hold higher volumes of risky assets on its balance sheet as a protection from insolvency. Real estate loans decline on impact of balance sheet shock; this negative effect dies out after 5 quarters, and later becomes positive, when banks are in a stronger position to lend. Remarkably, this negative effect of balance sheet shock on mortgages is reflected on the dynamics of total loans, which also go down on impact of a positive shock to banks capital ratio and start growing through the second year. This negative effect of capital ratio that I find for mortgages is in line with finding of Barajas et al. (2015), who use a different VAR specification to estimate the effect of capital ratio of banks on total loans volumes.

Lastly, it is worth mentioning that all the loans components respond to cost shock negatively, while the impact of positive real activity shock is positive on all the classes of loans. Augmenting the baseline model with additional variables does not change the sign of impulse responses to these two macroeconomic shocks. The effect of a positive innovation to real activity on safe assets is negative, what makes an evidence for banks' assets portfolio reallocation after a real activity shock from securities and cash to loans.

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<sup>30</sup>In this study I don't distinguish between commercial and residential real estate loans; I conjecture that corporate leverage is a significant determinant of the dynamics of the latter.

### 1.4.3 Discussion of results

The results presented here give evidence in favour of bank-lending channel, i.e. that the Federal Reserve can affect bank' loan supply schedules by changing reserves. I show that not only mortgages' and consumer loans' issuance declines following monetary contraction<sup>31</sup> as it has been shown, for example, in den Haan et al. (2007) and in Gertler and Gilchrist (1993). I demonstrate that C&I loans also go down after a shock to federal funds rate, if the risk and balance sheet variables are controlled for.

We show that importance of risk factors as determinants of C&I loans' dynamics is greater than for mortgages and consumer loans. Particularly, forecast error variance decomposition analysis suggests that credit risk is a critical determinant of business loans' volumes<sup>32</sup>, which, together with macroeconomic uncertainty, explains up to 29% of C&I loans' variance. Contrary to this, only up to 17% of business loans variance movements is explained by all macroeconomic factors together: real activity level, inflation and federal funds rate. This stands in marked contrast with the characteristics of consumer and real estate loans' issuance. Risk factors - uncertainty and portfolio credit risk - explain up to 12% of the variance of mortgages, while macroeconomic factors – up to 43%. For consumer loans' variance up to 26% is explained by risk factors, while macroeconomic factors explain 42%. Hence, comparing with two other classes of loans, the share of variance of business loans explained by risk factors is substantially higher than what is explained by macroeconomic factors. Therefore, unlike for mortgages and consumer loans, it is essential that risk factors are controlled for in a model that aims to provide a satisfactory explanation of the C&I loans' dynamics.

A possible reason for the impact of risk factors being critical for issuance of business loans and not for real estate and consumer loans is that risk associated with C&I loans is generally smaller than risk related to other two classes of loans. First, the rate on loans to corporate customers is normally floating, it is more flexible than a rate on consumer loans, for which the market structure is such that interest rates are less flexible. This allows banks to have the rate on C&I loans be adjusted to altering macroeconomic conditions. Hence, interest rate risk for this type of loans is minimized. Second, commercial and industrial lending is often a lending of relatively short maturity, comparing to other types of loans. This implies lower risk, as the probability of deterioration of borrower's financial conditions over a short period is lower than that over the longer horizon. Besides, shorter maturity increases frequency of loans' extensions, thus, banks revise borrowers' due diligence information and update their contract terms more frequently. This allows banks to re-optimize contract terms for business lending according to changing economic environment and to the financial state of a debtor. Third, closer ties between a bank and its creditors in the case of business loans allow the former to

<sup>31</sup>The interpretation of consumer and real estate loans reduction following monetary contraction is based on the fact that banks finance their long-term loans with short-term liabilities. Thus, mortgages, characterized by long maturity, and consumer loans with their small degree of flexibility of loan rates, are loans with comparatively low current-period profit margins. Current-period net earnings on these loans go down after monetary tightening, because interest rates on these loans changes by less than short-term interest rate. Hence, banks reduce issuance of consumer and real estate loans following monetary contraction.

<sup>32</sup>These results are confirmed by cross-correlation and Granger causality tests, see Tables 2 and 3 in Appendix A.

possess timely information about the latter, hereby attenuating informational asymmetries between them. This could be due to relationship lending, which facilitates monitoring of businesses. The outcome is the increased availability of funds to borrowers that have closer ties to lenders, what is found to be of particular relevance for business lending<sup>33</sup>. Forth, issuing business loans is generally less information-intensive than, for example, mortgages, what makes them easier to evaluate. Hence, monitoring costs for the C&I loans are smaller. Thus, commercial and industrial loans are characterized by lower level of risk comparing to mortgages and consumer loans.

When affected by heightened macroeconomic uncertainty or increased credit risk, business loans are likely to lose their perceived status of relatively safe asset, which in other (normal) conditions allows to earn a stable yield with comparatively low risk. Uncertainty and risk factors matter, because they induce banks to change expectations about loans profitability: when risk substantializes (for example, the rate of default on loans goes up), the return on C&I loans declines and/or gets more volatile. To compensate for this decline, risk premium goes up. Empirical evidence in Aksoy and Basso (2014) corroborates this consideration: they show that an increase in the US bank-level expected financial business profitability as measured by the expected mean forecast in earnings per share for major US financial institutions, leads to a significant decline in yield spreads next to variations in real output and inflation. In other words, when banks expect decline of their profits, they charge higher premium for loans issuance, and availability of loans reduces.

Hence, in the conditions of heightened macroeconomic uncertainty and greater credit risk banks would want to revise their portfolios of assets to take into account changed loans characteristics and the fact that business loans cannot be regarded as a safe asset anymore. The terms of business lending are revised more often due to relatively shorter maturity of C&I loans. As a result, the dynamics of business loans is more sensitive to risk factors than the dynamics of other types of loans' issuance. I conjecture that shorter maturity and generally lower riskiness might be the reasons why risk factors are more influential for dynamic regularities of commercial and industrial loans, than in case of real estate and consumer loans.

## 1.5 Conclusion

This chapter examines the dynamic properties of the banking sector loan components and safe assets holdings. I have estimated a range of structural vector autoregressive models by using Cholesky decomposition for shocks identification to resolve the puzzle of den Haan et al. (2007) of a positive response of business loans to monetary contraction and to identify the key determinants of the various assets in banks' portfolios. Testing vector autoregressive models for parameters' stability with the several versions of Chow tests enabled me to identify two structural breaks in the relationships between macroeconomic and credit variables

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<sup>33</sup>See, among others, Hoshi et al. (1991), Petersen (1999), Petersen and Rajan (1994), Chakraborty and Charles (2006), Bharath et al. (2011) for empirical evidence on that.



with the first break associated with the change in the US monetary policy in the beginning of 1980's and the second break related to the financial crisis of 2008-2009. Taking into account the identified structural break dates and extending the set of model variables with the leverage of corporate sector, credit risk, economic uncertainty and bank capital ratio allowed me to show that in contrast with the results of den Haan et al. (2007), commercial and industrial loans go down following monetary tightening in line with the predictions of the bank lending channel of monetary policy over all the time period subsamples analyzed.

I examined impulse response functions and results of the forecast error variance decomposition analysis of business loans, mortgages and consumer loans and found that the dynamic properties of these loan types are significantly different. First, the movements of business loans are driven primarily by positive innovations to credit risk, meaning it is critical to control for credit risk to eliminate the case of omitted variable bias, when trying to explain the business loans volumes' dynamics. The changes in consumer loans' issuance are attributed primarily to real activity and inflation shocks and to shock to credit risk. The variance of real estate loans is driven by cost shocks, monetary policy shocks and innovations to the corporate sector indebtedness. At the same time uncertainty shock is the most important determinant of the banking sector safe assets' movements.

Second, I demonstrated that responses of the different classes of loans to the most types of structural shocks among are heterogeneous. In particular, consumer loans, business loans and mortgages respond to uncertainty shock, a shock to corporate sector indebtedness, a shock to capital ratio and to shock to credit risk differently. Consumer loans feature an increase to a positive shock to corporate sector leverage and a brief increase to a positive innovation to uncertainty, while the responses of commercial and industrial loans and of real estate loans to these two types of shocks are negative. On the other hand, smaller volume of mortgages is issued following a positive shock to bank capital, whereas business and consumer loans respond to it positively. Finally, business and consumer loans go down significantly, when a positive shock to credit risk hits, whereas real estate loans don't feature a significant response to it.

Uncertainty shocks are found to induce asset portfolio reallocation by banks: following a positive innovation to uncertainty, issuance of business loans goes down, while safe assets' holdings increase. This result is robust to a series of robustness checks, specifically, to ordering of variables in the VAR, to measure of uncertainty used and to asset representation in the VAR – either in levels or as a share of total portfolio.

## 1.6 Appendix

### 1.6.1 Data

The following paragraphs provide details on data definitions, sources and treatment.

#### *Real GDP*

Real Gross Domestic Product, Billions of Chained 2009 Dollars, Quarterly, Seasonally Adjusted, downloaded from Fred II (GDPIC1), see <http://research.stlouisfed.org/fred2/>. Source: U.S. Department of Commerce: Bureau of Economic Analysis. Growth variable is annualized quarter to quarter growth rates.

#### *GDP deflator*

Gross Domestic Product: Implicit Price Deflator, Index 2009=100, Quarterly, Seasonally Adjusted, downloaded from Fred II (GDPDEF), see <http://research.stlouisfed.org/fred2/>. Source: U.S. Department of Commerce: Bureau of Economic Analysis.

#### *Federal funds rate*

Effective Federal Funds Rate, Percent, Quarterly, Not Seasonally Adjusted, downloaded from Fred II (FEDFUNDS), see <http://research.stlouisfed.org/fred2/>. Source: Board of Governors of the Federal Reserve System (US).

#### *Short-term interest rate*

3-Month Treasury Bill: Secondary Market Rate, average of monthly data, downloaded from Fred II (TB3MS), see <http://research.stlouisfed.org/fred2/>. Sources: Board of Governors of the Federal Reserve System.

#### *Nonborrowed reserves of depository institutions*

Aggregate Reserves of Depository Institutions and the Monetary Base (equals total reserves less total borrowings from the Federal Reserve), Millions of Dollars, Quarterly, Not Seasonally Adjusted. Downloaded from Fred II (TOTRESNS and BORROW), see <http://research.stlouisfed.org>. Source: Board of Governors of the Federal Reserve System (US).

#### *Commercial and industrial loans*

Commercial and Industrial Loans, All Commercial Banks, Billions of Dollars, Quarterly, Seasonally Adjusted, downloaded from Fred II (BUSLOANS), see <http://research.stlouisfed.org/fred2/>. Source: Board of Governors of the Federal Reserve System (US). Deflated with GDP implicit price deflator.

#### *Real estate loans*

Real estate loans, All Commercial Banks, Billions of Dollars, Monthly, Not Seasonally Adjusted, downloaded from Data Download Program (H8/H8/B1026NCBDM). See <http://www.federalreserve.gov/datadownload/>. Quarterly series are averages of monthly data. Source: Board of Governors of the Federal Reserve System (US). Deflated with GDP implicit price deflator.

#### *Consumer loans*

Consumer loans, All Commercial Banks, Billions of Dollars, Monthly, Not Seasonally Adjusted, downloaded from Data Download Program (H8/H8/B1029NCBDM). See <http://www.federalreserve.gov/datadownload/>. Quarterly series are averages of monthly

data. Source: Board of Governors of the Federal Reserve System (US). Deflated with GDP implicit price deflator.

#### ***Total loans***

Loans and leases in bank credit, All Commercial Banks, Billions of Dollars, Monthly, Not Seasonally Adjusted, downloaded from Data Download Program (H8/H8/B1020NCBAM). See <http://www.federalreserve.gov/datadownload/>. Quarterly series are averages of monthly data. Source: Board of Governors of the Federal Reserve System (US). Deflated with GDP implicit price deflator.

#### ***Capital ratio***

Calculated as a ratio of Total Equity Capital for Commercial Banks to Total Assets of Commercial Banks. Seasonally Adjusted with X-13ARIMA-SEATS algorithm from the US Census Bureau.

Total Equity Capital for Commercial Banks in the U.S., Thousands of Dollars, Quarterly, Not Seasonally Adjusted, downloaded from Fred II (USTEQC), see <http://research.stlouisfed.org/fred2/>. Source: Federal Financial Institutions Examination Council.

Total Assets of Commercial Banks in the U.S., Millions of Dollars, Quarterly, Not Seasonally Adjusted, downloaded from Data Download Program (H8/H8/B1151NCBDM). See <http://www.federalreserve.gov/datadownload/>. Source: Board of Governors of the Federal Reserve System (US).

#### ***Charge-off rates***

Charge-off rate on business loans, consumer loans, real estate loans and total loans, all commercial banks, Percentage, Quarterly, Seasonally Adjusted, downloaded from Data Download Program (CHGDEL), see <http://www.federalreserve.gov/datadownload/>. Source: Board of Governors of the Federal Reserve System (US).

#### ***Leverage***

Calculated as a ratio of Total assets to Net worth of nonfinancial corporate business. Seasonally Adjusted with X-13ARIMA-SEATS algorithm from the US Census Bureau.

Total assets of nonfinancial corporate business, Millions of Dollars, Quarterly, Not Seasonally Adjusted, downloaded from Data Download Program (Z1/Z1/FL102000005.Q).

See <http://www.federalreserve.gov/datadownload/>. Source: Board of Governors of the Federal Reserve System (US).

Net worth of nonfinancial corporate business, Millions of Dollars, Quarterly, Not Seasonally Adjusted, downloaded from Data Download Program (Z1/Z1/FL102090005.Q).

See <http://www.federalreserve.gov/datadownload/>. Source: Board of Governors of the Federal Reserve System (US).

#### ***Safe assets***

Calculated as a sum of Cash assets and Treasury and agency securities of all commercial banks.

Cash assets, all commercial banks, Millions of Dollars, Monthly, Seasonally Adjusted, downloaded from Data Download Program (H8/H8/B1048NCBAM).

See <http://www.federalreserve.gov/datadownload/>. Quarterly series are averages of monthly

data. Source: Board of Governors of the Federal Reserve System (US). Deflated with GDP implicit price deflator.

Treasury and agency securities, all commercial banks, Millions of Dollars, Monthly, Seasonally Adjusted, downloaded from Data Download Program (H8/H8/B1003NCBAM).

See <http://www.federalreserve.gov/datadownload/>. Quarterly series are averages of monthly data. Source: Board of Governors of the Federal Reserve System (US). Deflated with GDP implicit price deflator.

#### ***Uncertainty – news-based index***

A normalized index of the volume of news articles discussing economic policy uncertainty, constructed by the Economic Policy Uncertainty project, Quarterly, Not Seasonally Adjusted. Downloaded from <http://www.policyuncertainty.com/>.

#### ***Uncertainty – composite policy uncertainty index***

An overall index measuring policy-related economic uncertainty, constructed by the Economic Policy Uncertainty project, Quarterly, Not Seasonally Adjusted. Downloaded from <http://www.policyuncertainty.com/>.

#### ***Uncertainty – VIX index, the stock market option-based implied volatility***

The Chicago Board Options Exchange volatility index VIX, Quarterly (aggregation method - average), Not Seasonally Adjusted, downloaded from Fred II (VIXCLS), see <http://research.stlouisfed.org>. Source: Chicago Board Options Exchange.

#### ***Uncertainty – cross-sectional standard deviation of firms' pretax profit growth***

The within-quarter cross-sectional spread of pretax profit growth rates normalized by average sales, using data on firms with at least 150 quarters of available data<sup>34</sup> taken from Compustat quarterly accounts and is calculated by Bloom (2009) according to

$$pg_t = \frac{\pi_t - \pi_{t-1}}{0.5 (S_t - S_{t-1})},$$

where  $\pi_t$  and  $S_t$  are firm's profit and sales respectively, where the highest and the lowest 0.05% values of  $pg_t$  are disregarded such that the resulting series is not driven by outliers. Downloaded from <https://people.stanford.edu/nbloom/sites/default/files/replication.zip>. Source: Nicholas Bloom data.

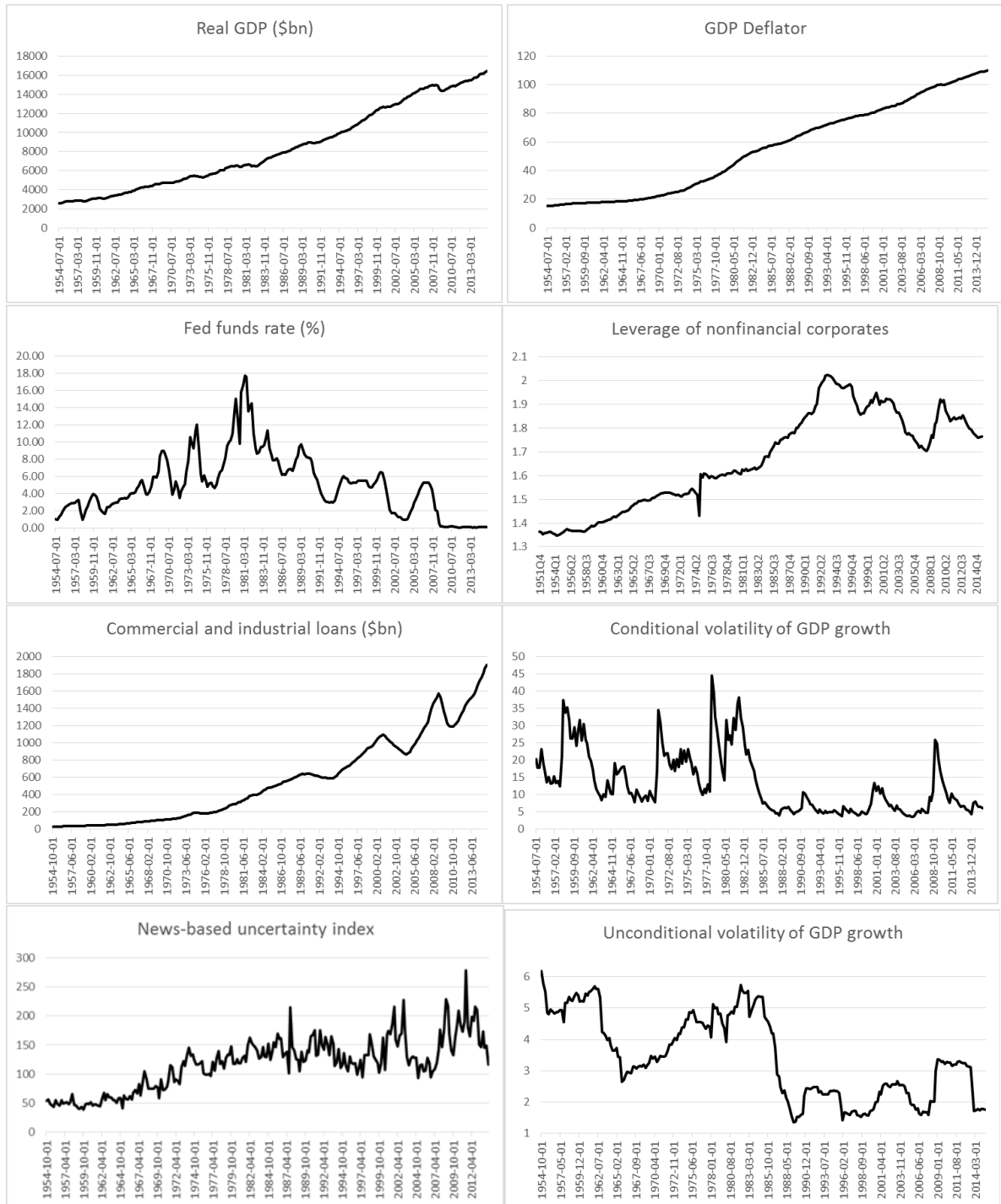
#### ***Uncertainty – cross-firm spread of stock returns***

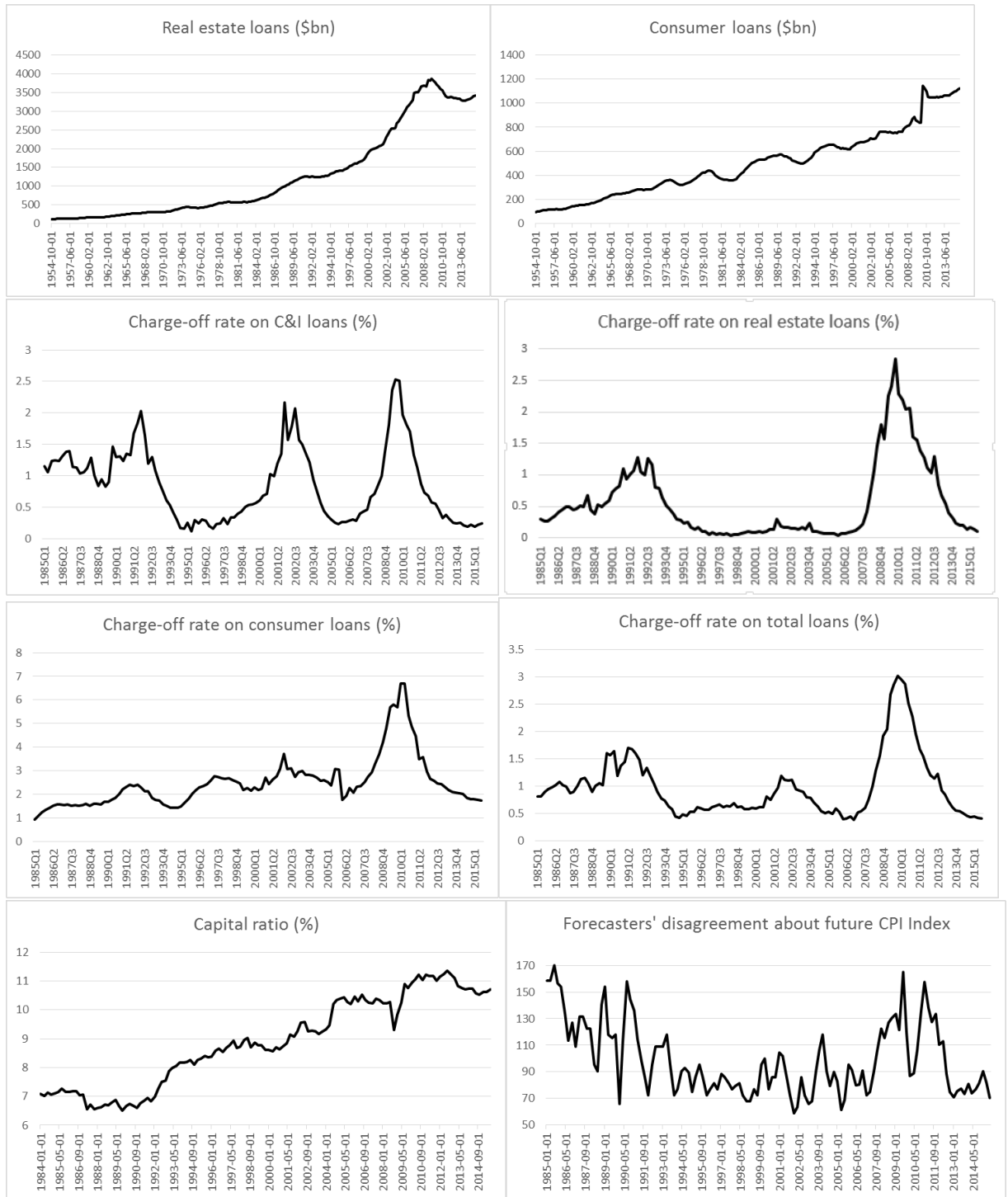
The interquartile range of firms' monthly stock returns for all public firms with no less than 300 months of data from the Center of Research in Security Prices over 1960-2010. The returns are windsorized at the top and the bottom 0.5% growth rates to eliminate the extreme values to affect the series. Downloaded from [https://people.stanford.edu/nbloom/sites/default/files/census\\_data.zip](https://people.stanford.edu/nbloom/sites/default/files/census_data.zip). Source: Nicholas Bloom data.

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<sup>34</sup>This is done to minimize the effects of sample composition changes.

Figure 1.1: Variables' series in levels.





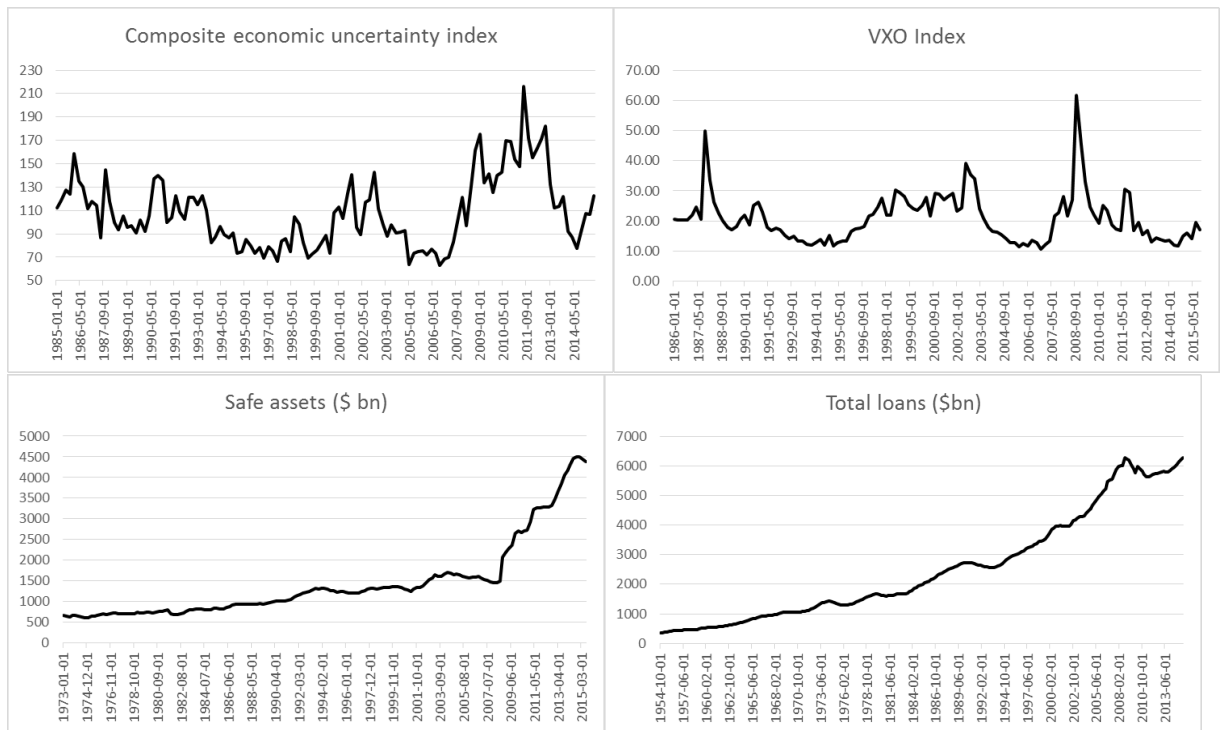


Figure 1.2: Measures of macroeconomic uncertainty

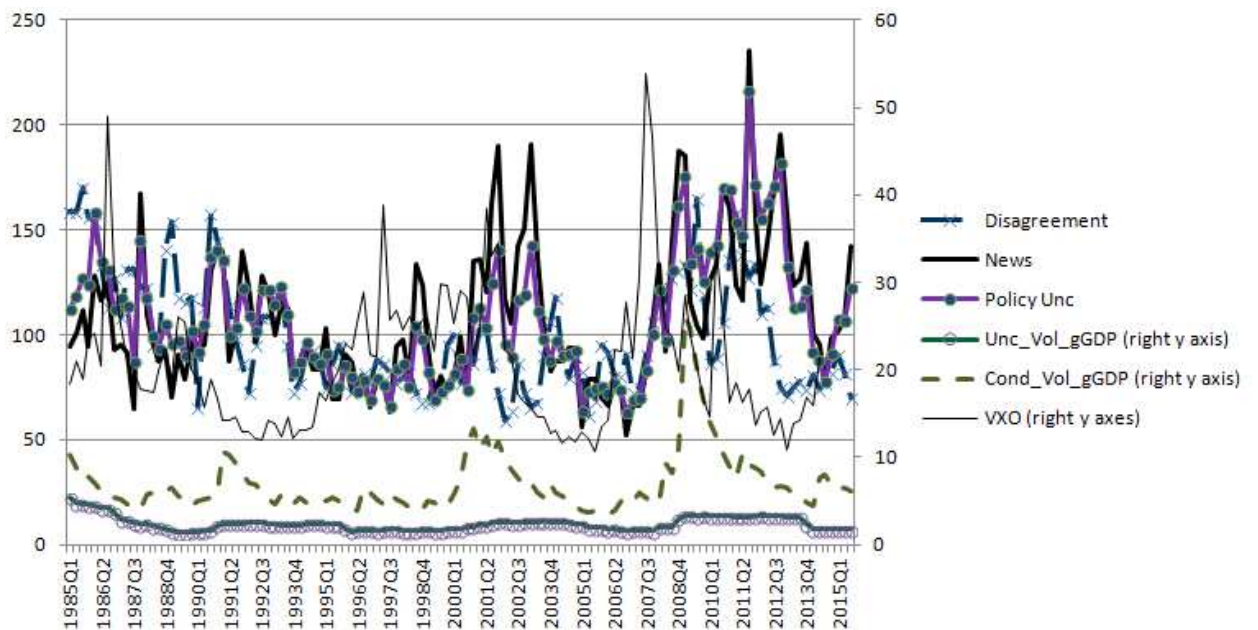


Figure 1.3: Assets in portfolios of commercial banks

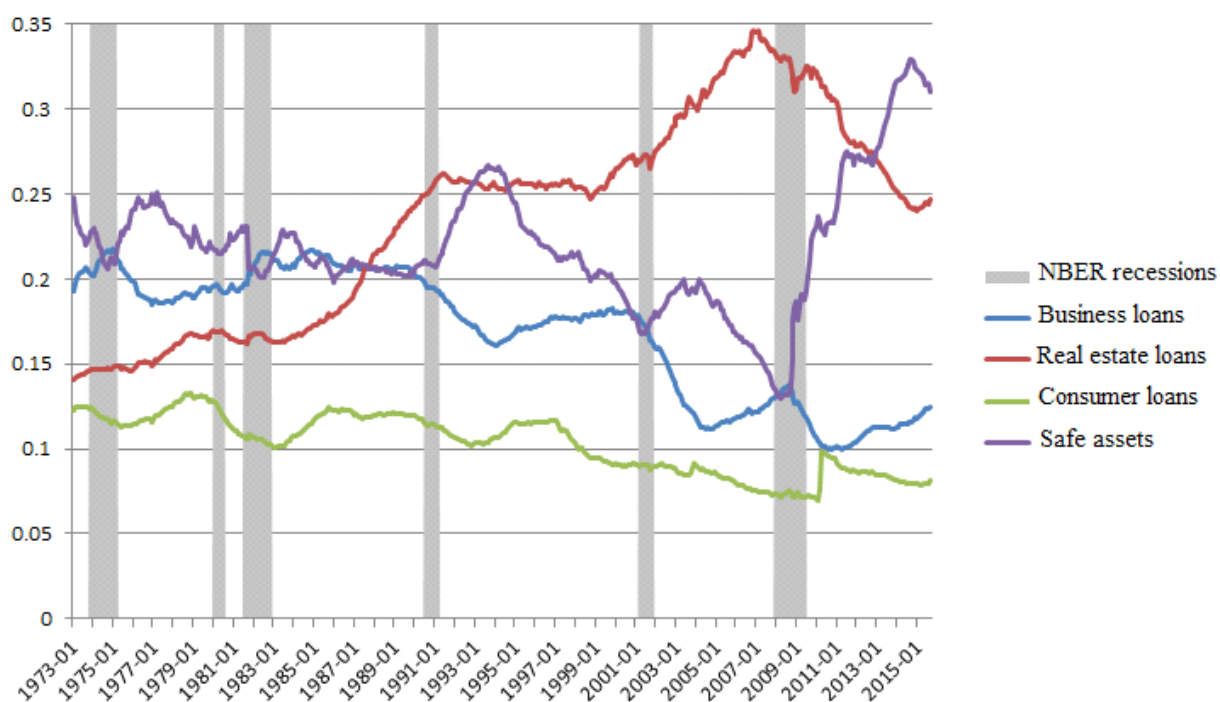


Table 1.4: Loan components and safe assets in commercial banks' portfolios

	Series avail- able from	Percentage of to- tal assets
Commercial and industrial loans	1947Q1	10-21%
Real estate loans	1947Q1	14-34%
Consumer loans	1947Q1	7-13%
Safe assets	1973Q1	13-34%
Aforementioned asset types		66-79%



Table 1.5: Cross-correlations of bank assets with macro and financial variables

<b>Cross-correlations and lead-lag relationship with</b>	<b>Commercial and industrial loans</b>	<b>Real estate loans</b>	<b>Consumer loans</b>	<b>Safe assets</b>
Real GDP	0.39: 2Q lag	0.26: 1Q lag	0.15: contempor.	-0.22: 3Q lag
GDP deflator	-0.20: 5Q lag	-0.19: 4Q lag	-0.20: 4Q lag	-0.19: 2Q lead
Federal funds rate	0.29: 1Q lead	0.22: 2Q lead	-0.16: 5Q lag	-0.19: 3Q lag
Leverage of corporates	-0.20: 5Q lag	N/S	N/S	N/S
Charge-off rate	-0.71: 1Q lag	-0.62: 4Q lag	0.25: contempor.	0.37: 2Q lead
Capital ratio	-0.35: contempor.	-0.31: contempor.	-0.42: 6Q lag	-0.38: contempor.
Uncertainty: conditional volatility of GDP growth	N/S	N/S	N/S	N/S
Uncertainty: unconditional volatility of GDP growth	-0.25: 5Q lag	-0.17: 1Q lag	N/S	0.28: contempor.
Uncertainty: news-based index	-0.45: 2Q lag	-0.35: 2Q lag	N/S	0.28: contempor.
Uncertainty: forecasters' disagreement	-0.22: 3Q lag	N/S	N/S	N/S
Uncertainty: composite policy uncertainty index (level)	-0.41: 2Q lags	-0.39: 2Q lag	N/S	0.29: 1Q lead
Uncertainty: VIX index	-0.58: 4Q lag	N/S	N/S	0.34: contempor.

Note. The variables' growth rates are analyzed. Uncertainty measures, charge-off rates, reported changes in lending standards, in demand for loans and in banks' tolerance of risk are in taken levels. Quarterly data is used. Lag and lead qualifications are given for the variables in columns (classes of assets) with respect to variables in rows (for example, real GDP); 2Q lag for commercial and industrial loans with real GDP means GDP values lead loan volumes by 2 quarters. N/S stands for statistically non-significant result. Contempor. stand for contemporaneous relationship.

Table 1.6: Pairwise Granger causality tests

Variables and the direction of Granger causation	F-statistic	Prob.
<b>GDP C&amp;I loans</b>	9.08832	0.0002
C&I loans GDP	0.75140	0.4727
<b>GDP deflator C&amp;I loans</b>	3.14953	0.0447
<b>C&amp;I loans GDP deflator</b>	4.11949	0.0174
Federal funds rate C&I loans	1.17991	0.3091
<b>C&amp;I loans Federal funds rate</b>	7.58342	0.0006
Corporate leverage C&I loans	2.74632	0.0661
C&I loans Corporate leverage	2.42014	0.0910
<b>Charge-off rate C&amp;I loans</b>	9.36715	0.0002
<b>C&amp;I loans Charge-off rate</b>	3.19219	0.0447
<b>Capital ratio C&amp;I loans</b>	8.59464	0.0003
<b>C&amp;I loans Capital ratio</b>	3.86757	0.0236
Conditional volatility of GDP growth C&I loans	0.50366	0.6049
<b>C&amp;I loans Conditional volatility of GDP growth</b>	3.80796	0.0234
<b>Unconditional volatility of GDP growth C&amp;I loans</b>	7.46891	0.0007
C&I loans Unconditional volatility of GDP growth	0.74585	0.4754
<b>VIX index C&amp;I loans</b>	8.38036	0.0004
C&I loans VIX index	2.03600	0.1361
<b>News-based uncertainty index C&amp;I loans</b>	3.72973	0.0254
<b>C&amp;I loans News-based uncertainty index</b>	12.6213	6.E-06
Forecasters' disagreement about future CPI C&I loans	1.21896	0.2993
C&I loans Forecasters' disagreement about future CPI	0.21120	0.8099
Composite economic uncertainty index C&I loans	2.20456	0.1149
C&I loans Composite economic uncertainty index	1.41788	0.2464

Note. The pairwise Granger causality tests were run between the volume of commercial and industrial loans and one of macro, financial or uncertainty variables. The cases of significant Granger causality are shown in bold. The null hypothesis is that one variable does not Granger-cause another variable, 95% significance level is used. The tests are run using 2 lags, what corresponds to the number of lags used in the vector autoregression models, where they are selected using relevant information criteria.

Table 1.7: Conditional heteroskedasticity of GDP growth

Variable	Coefficient	Std.Error	z-statistic	p-value
$c$	2.11	0.28	7.66	0.00
$\theta$	0.37	0.07	5.42	0.00
$\omega$	0.48	0.29	1.68	0.09
$\alpha$	0.18	0.04	4.07	0.00
$\beta$	0.80	0.04	19.37	0.00

Note. GARCH(1,1) model parameters' estimates.

### 1.6.2 Structural break tests

To test for structural breaks I use the versions of Chow tests suggested by Canova (2007), Lutkepohl (2001) and Doornik and Hendry (1997).

For the fixed break date that might have occurred in period  $T_B$  the model is estimated on the full sample data of  $T$  observations and from the first  $T_1$  and the last  $T_2$  observations, where  $T_1 < T_B$  and  $T_2 \leq T - T_B$ . The resulting residuals are denoted by  $\hat{u}_t$ ,  $\hat{u}_t^1$  and  $\hat{u}_t^2$ , respectively. The following covariance matrices are calculated:

$$\widehat{\Sigma}_{1,2} = T_1^{-1} \sum_{t=1}^{T_1} \hat{u}_t \hat{u}_t' + T_2^{-1} \sum_{t=T-T_2+1}^T \hat{u}_t \hat{u}_t',$$

$$\widehat{\Sigma}_1 = T_1^{-1} \sum_{t=1}^{T_1} \hat{u}_t^1 \hat{u}_t^{1'}$$

$$\text{and } \widehat{\Sigma}_2 = T_2^{-1} \sum_{t=T-T_2+1}^T \hat{u}_t^2 \hat{u}_t^{2'}.$$

Using this notation, the break-point Chow test statistics is calculated as:

$$\lambda_{BP} = (T_1 + T_2) \log \left| \widehat{\Sigma}_{1,2} \right| - T_1 \log \left| \widehat{\Sigma}_1 \right| - T_2 \log \left| \widehat{\Sigma}_2 \right| \sim \chi^2(k),$$

where  $k$  is the number of restrictions imposed by assuming a constant coefficient model for the full sample period, that is,  $k$  is the difference between the sum of the number of coefficients estimated in the first and last subperiods and the number of coefficients in the full sample model. The null hypothesis of the model's parameters constancy is rejected if the value of the test statistic  $\lambda_{SS}$  is large.

The sample-split Chow test statistics is obtained under the assumption that the residual covariance matrix is constant. This statistics also checks the null hypothesis against the alternative that the coefficients of the VAR models may vary and is calculated as:

$$\lambda_{SS} = (T_1 + T_2) \left[ \log \left| \widehat{\Sigma}_{1,2} \right| - \left| T^{-1} \left( T_1 \widehat{\Sigma}_1 + T_2 \widehat{\Sigma}_2 \right) \right| \right] \sim \chi^2(k)$$

The Chow forecast methodology tests the null against the alternative that all the coefficients including the residual variance-covariance matrix vary. It rejects the null hypothesis of constant parameters for the large values of test statistic. The test statistic is calculated as:

$$\lambda_{CF} = \frac{1 - (1 - R_r^2)^{\frac{1}{s}}}{(1 - R_r^2)^{\frac{1}{s}}} * \frac{Ns - q}{nk} \sim F(nk, Ns - q),$$

where  $n$  is a number of time series considered,  $s = \left( \frac{n^2 k^2 - 4}{n^2 + k^2 - 5} \right)^{\frac{1}{2}}$ ,  $q = \frac{nk}{2} + 1$ ,

$$N = T - v - k - (n - k + 1)/2$$

$$R_r^2 = 1 - \left( \frac{\bar{t}}{T} \right)^n \left| \widehat{\Sigma}_1 \right| \left( \left| \widehat{\Sigma}_{1,2} \right| \right)^{-1}.$$

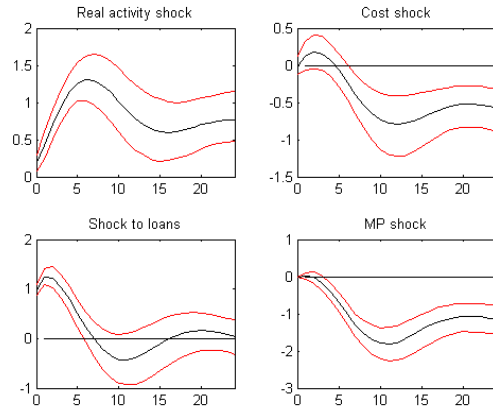
When the break date is treated as unknown, Chow tests are performed repeatedly for a range of potential break dates  $T_B$ , as suggested by Canova (2007) and Lutkepohl (2001). The value of split-sample test statistic is maximized over the interval  $[t_1, t_2]$ , where the break is

suspected to have happened:  $\sup_{T_B \in T} T \subset [t_1, t_2]$ . The asymptotic distribution of the sup test statistic is not  $\chi^2$ , but of a different type, see Andrews (1993), Andrews and Ploberger (1994) and Andrews (2003).

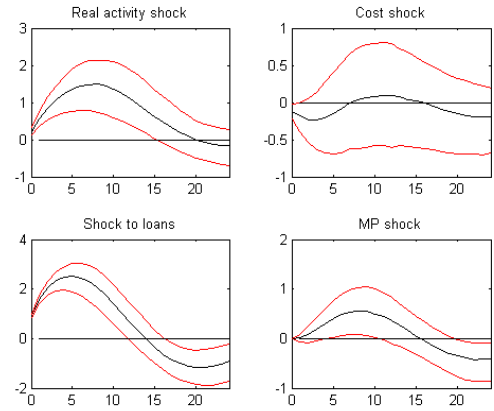
### 1.6.3 Impulse response functions and forecast error variance decomposition

Figure 1.4: Responses of commercial and industrial loans to shocks in the baseline model

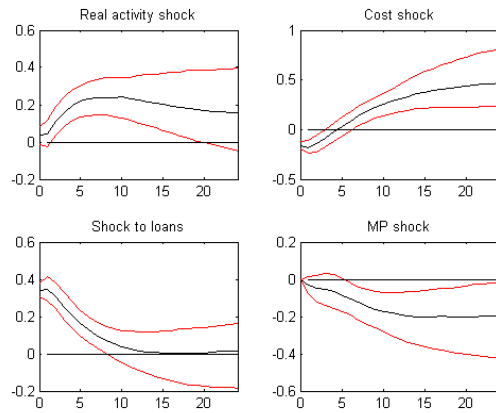
A. 1954Q4-1979Q4



B. 1983Q1-2007Q4



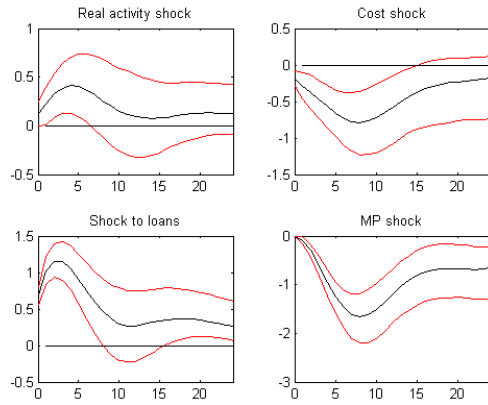
C. 2010M4-2015M12



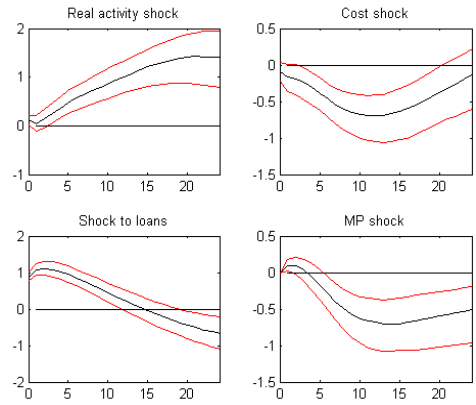
Note. The impulse responses are based on the benchmark specification: the federal funds rate is a monetary policy measure,  $X_{2t}$  is empty (all the variables are in  $X_{1t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). Y axis units – percents, X axis units – quarters.

Figure 1.5: Responses of real estate loans to shocks in the baseline model

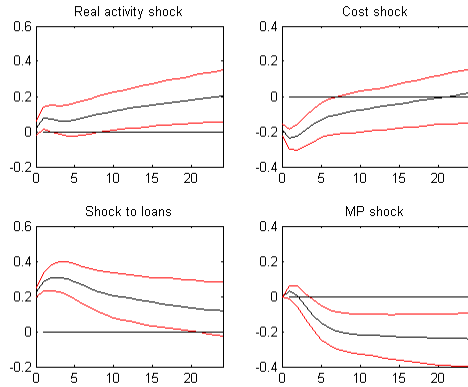
A. 1954Q1-1979Q4



B. 1983Q1-2007Q4



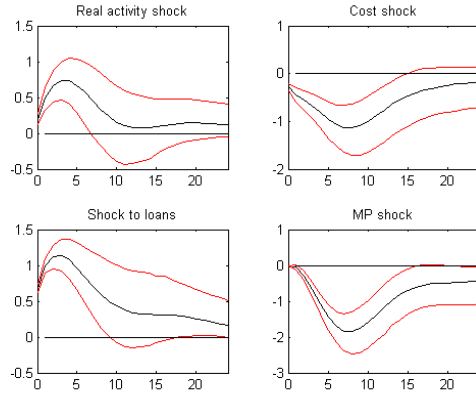
C. 2010M4-2015M12



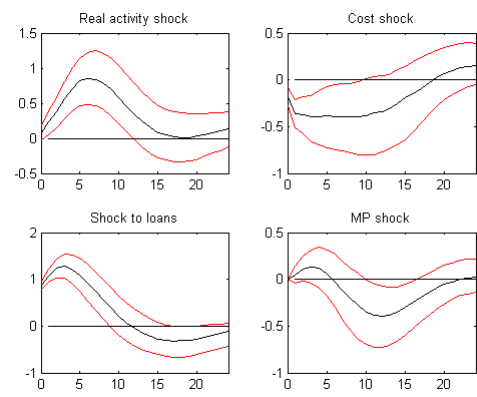
Note. The impulse responses are based on the benchmark specification: the federal funds rate is a monetary policy measure,  $X_{2t}$  is empty (all the variables are in  $X_{1t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). Y axis units – percents, X axis units – quarters.

Figure 1.6: Responses of consumer loans to shocks in the baseline model

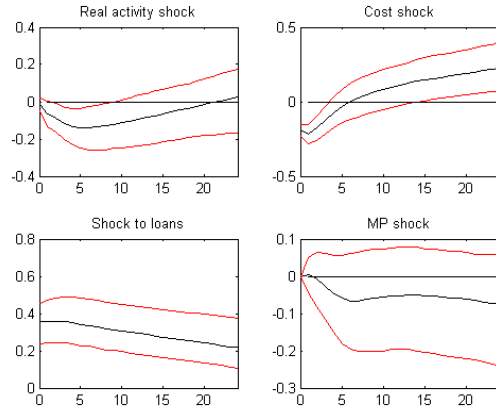
A. 1954Q1-1979Q4



B. 1983Q1-2007Q4



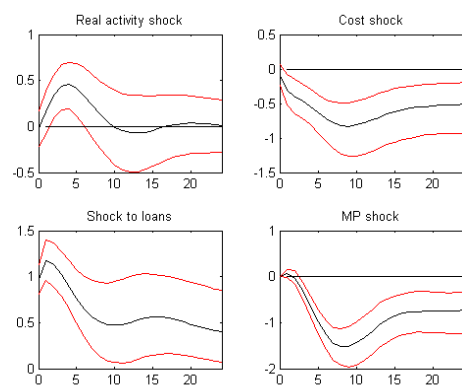
C. 2010M4-2015M12



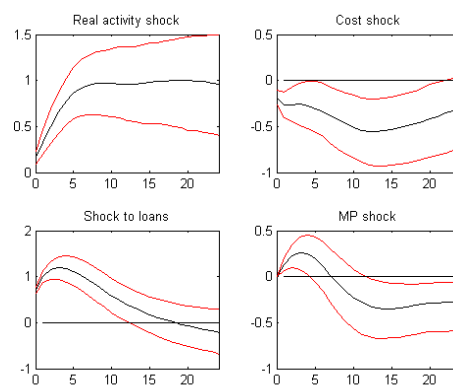
Note. The impulse responses are based on the benchmark specification: the federal funds rate is a monetary policy measure,  $X_{2t}$  is empty (all the variables are in  $X_{1t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). Y axis units – percents, X axis units – quarters.

Figure 1.7: Responses of total loans to shocks in the baseline model

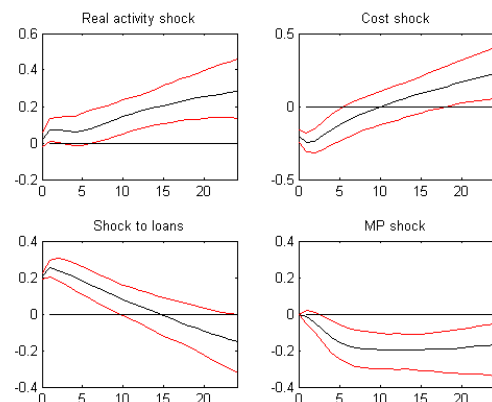
A. 1954Q4-1979Q4



B. 1983Q1-2007Q4



C. 2010M4-2015M12

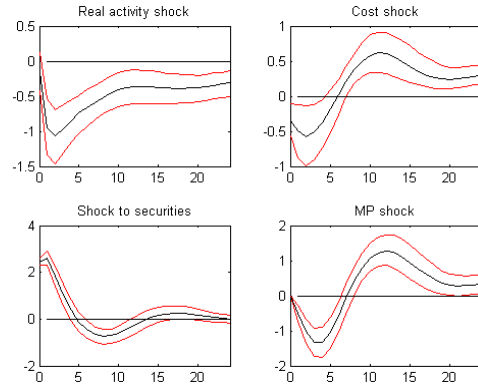


Note. The impulse responses are based on the benchmark specification: the federal funds rate is a monetary policy measure,  $X_{2t}$  is empty (all the variables are in  $X_{1t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). Y axis units – percents, X axis units – quarters.

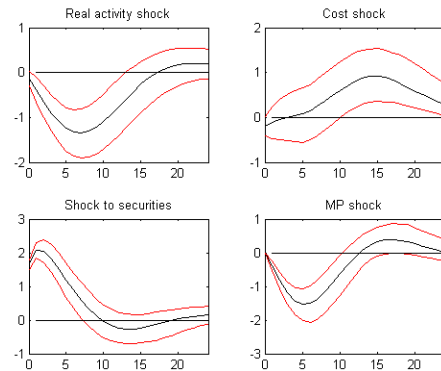


Figure 1.8: Responses of Treasury and agency securities in banks' assets to shocks in the baseline model

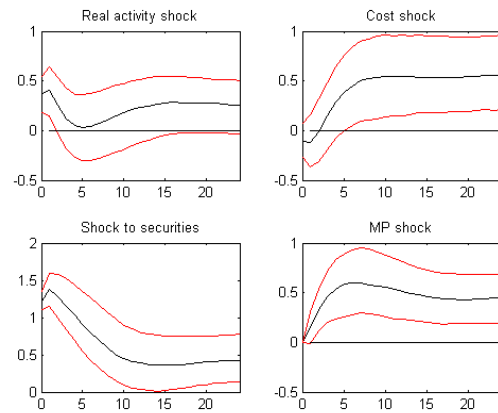
A. 1954Q4-1979Q4



B. 1983Q1-2007Q4



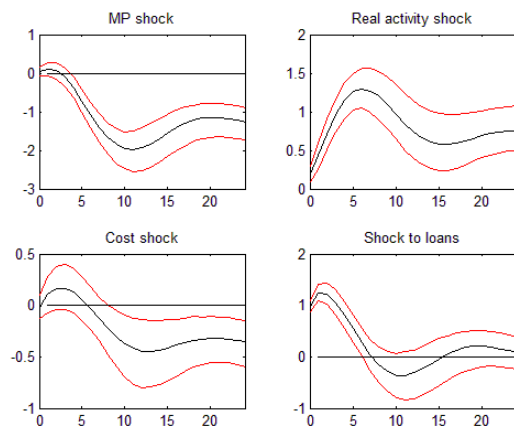
C. 2010M4-2015M12



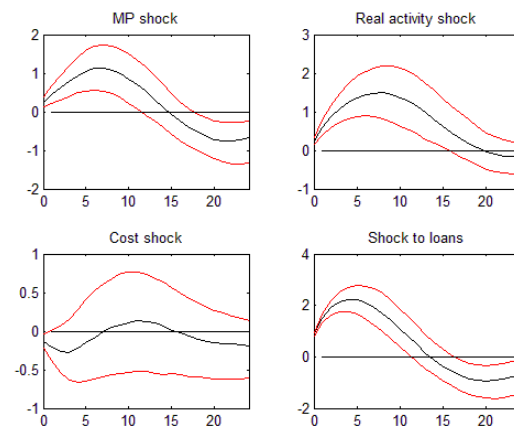
Note. The impulse responses are based on the benchmark specification: the federal funds rate is a monetary policy measure,  $X_{2t}$  is empty (all the variables are in  $X_{1t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). Y axis units – percents, X axis units – quarters.

Figure 1.9: Responses of commercial and industrial loans to shocks in the baseline model, alternative identification

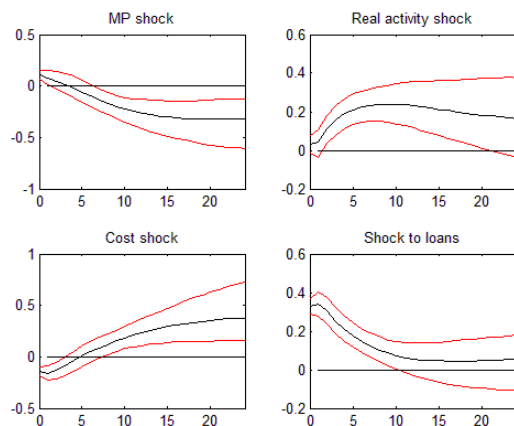
A. 1954Q4-1979Q4



B. 1983Q1-2007Q4



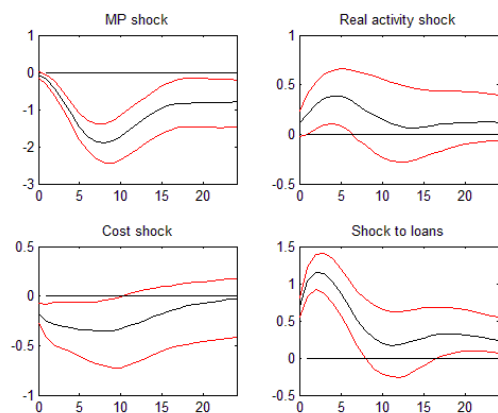
C. 2010M4-2015M12



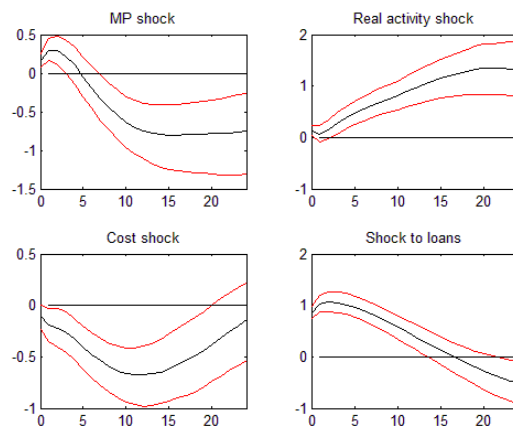
Note. The impulse responses are based on the alternative specification: the federal funds rate is a monetary policy measure,  $X_{1t}$  is empty (all the variables are in  $X_{2t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). Y axis units – percents, X axis units – quarters.

Figure 1.10: Responses of real estate loans to shocks in the baseline model, alternative identification

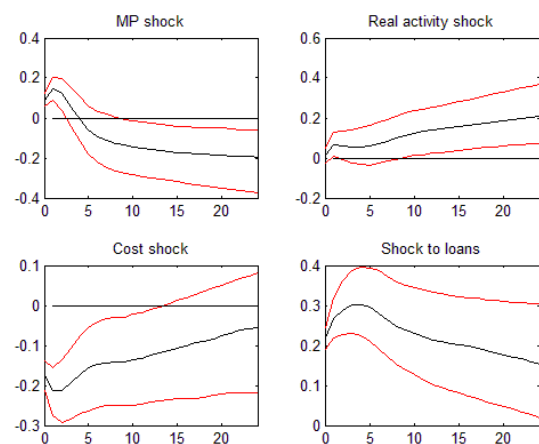
A. 1954Q4-1979Q4



B. 1983Q1-2007Q4



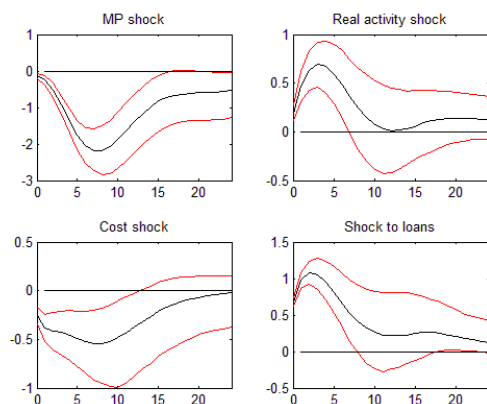
C. 2010M4-2015M12



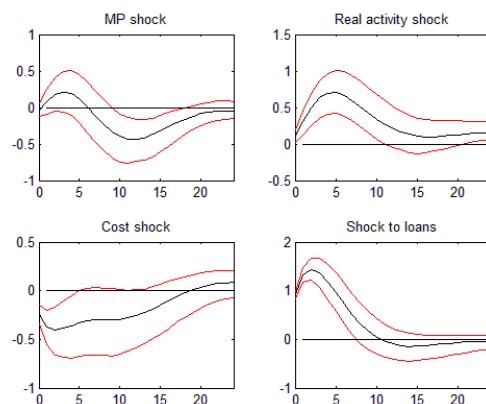
Note. The impulse responses are based on the alternative specification: the federal funds rate is a monetary policy measure,  $X_{1t}$  is empty (all the variables are in  $X_{2t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). Y axis units – percents, X axis units – quarters.

Figure 1.11: Responses of consumer loans to shocks in the baseline model, alternative identification

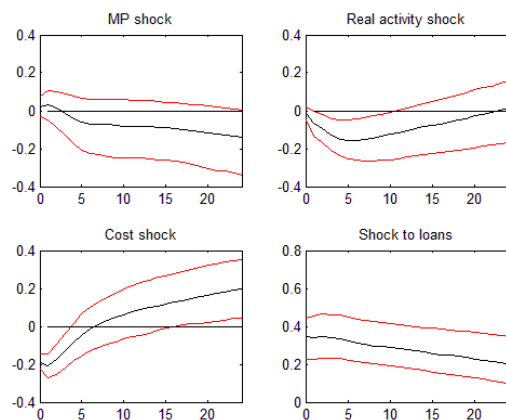
A. 1954Q4-1979Q4



B. 1983Q1-2007Q4



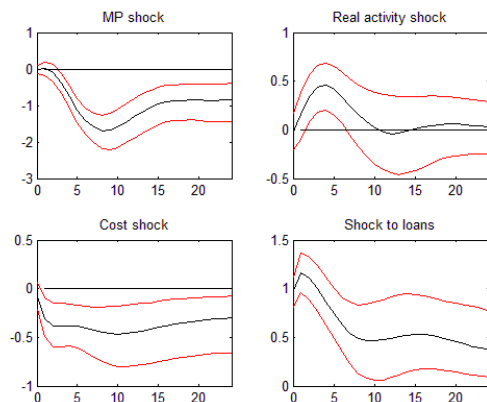
C. 2010M4-2015M12



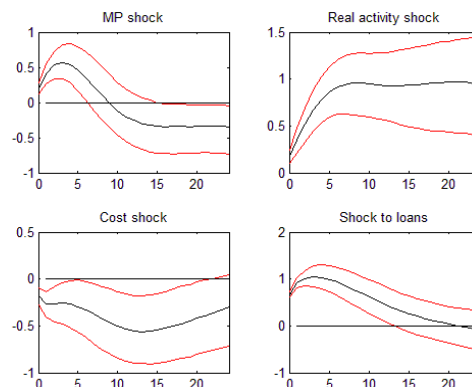
Note. The impulse responses are based on the alternative specification: the federal funds rate is a monetary policy measure,  $X_{1t}$  is empty (all the variables are in  $X_{2t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). Y axis units – percents, X axis units – quarters.

Figure 1.12: Responses of total loans to shocks in the baseline model, alternative identification

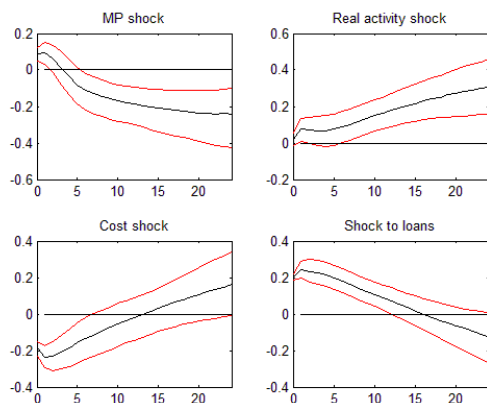
A. 1954Q4-1979Q4



B. 1983Q1-2007Q4



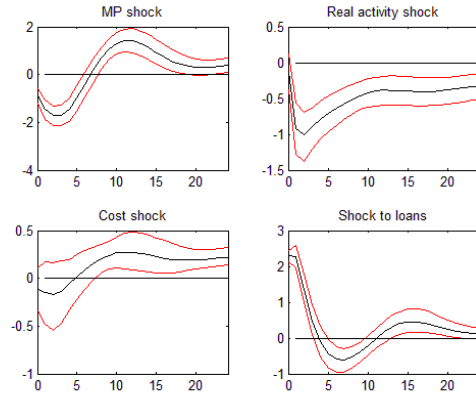
C. 2010M4-2015M12



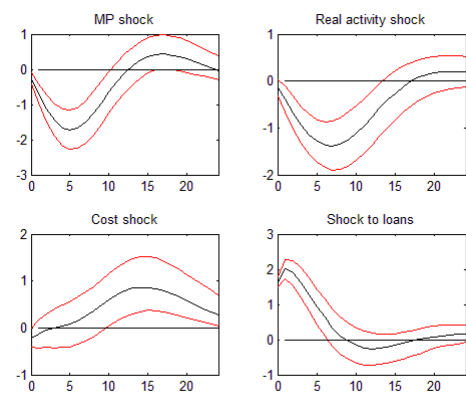
Note. The impulse responses are based on the alternative specification: the federal funds rate is a monetary policy measure,  $X_{1t}$  is empty (all the variables are in  $X_{2t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). Y axis units – percents, X axis units – quarters.

Figure 1.13: Responses of Treasury and agency securities to shocks in the baseline model, alternative identification

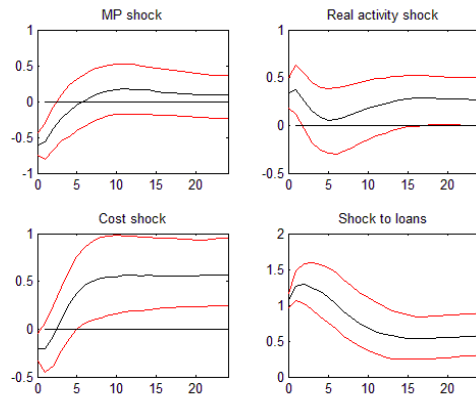
A. 1954Q1-1979Q4



B. 1983Q1-2007Q4



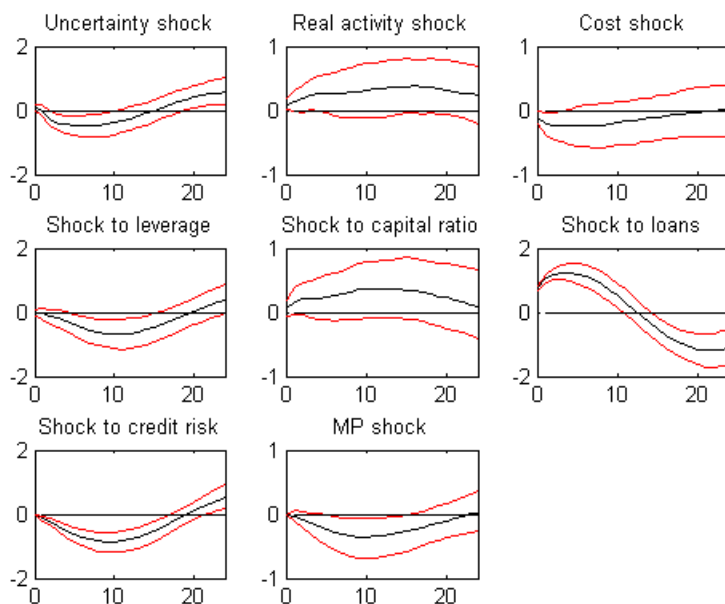
C. 2010M4-2015M12



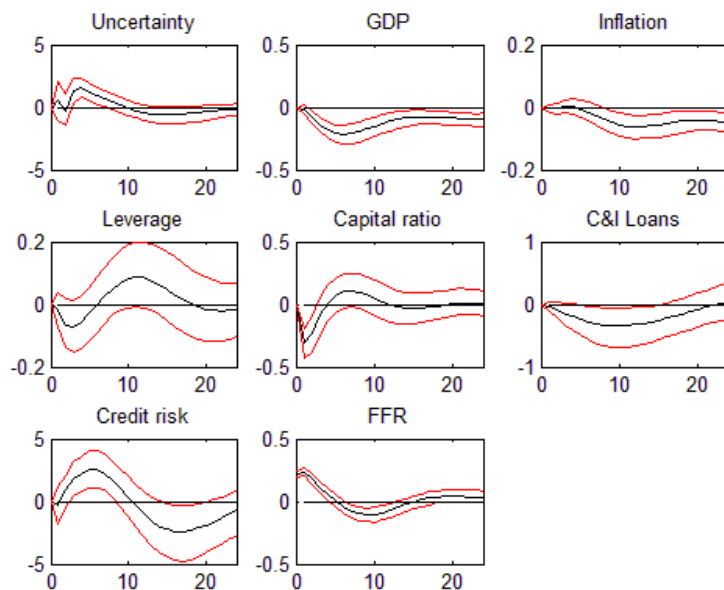
Note. The impulse responses are based on the alternative specification: the federal funds rate is a monetary policy measure,  $X_{1t}$  is empty (all the variables are in  $X_{2t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). Y axis units – percents, X axis units – quarters.

Figure 1.14: Impulse response functions, the extended model with commercial and industrial loans, uncertainty measure – news-based uncertainty index

A. Responses of commercial and industrial loans to various shocks, in %.

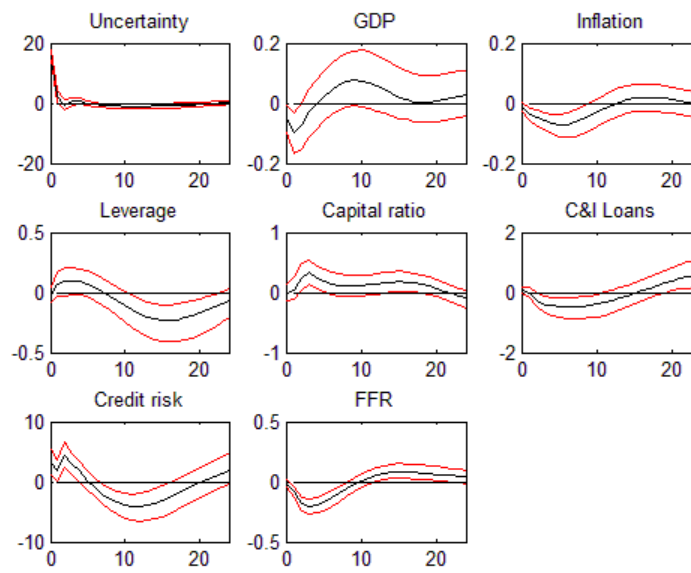


B. Impulse response functions to monetary policy shock (monetary contraction), in %.



Note. The impulse responses are based on the benchmark specification: the federal funds rate is a monetary policy measure,  $X_{2t}$  is empty (all the variables are in  $X_{1t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). According to AIC, the VAR order includes two lags. Y axis units – percents, X axis units – quarters.

C. Impulse response functions to uncertainty shock, in %.



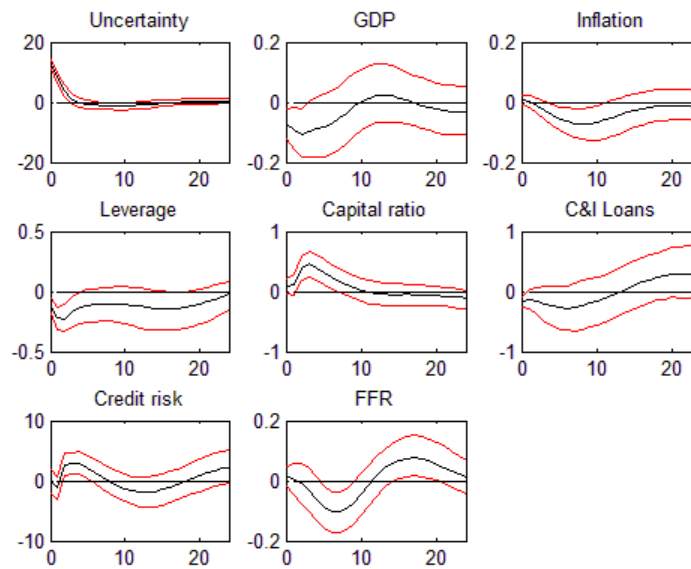
Note. The impulse responses are based on the benchmark specification: the federal funds rate is a monetary policy measure,  $X_{2t}$  is empty (all the variables are in  $X_{1t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). According to AIC, the VAR order includes two lags. Y axis units – percents, X axis units – quarters.



Table 1.8: Forecast error variance decomposition of commercial and industrial loans in the extended model, uncertainty measure – news-based uncertainty index

p/v	Unc	GDP	Infl	Levera	Cap ra	C&I lo	Ch off	FFR
1	0.00	0.01	0.02	0.00	0.01	0.95	0.00	0.00
2	0.00	0.01	0.03	0.00	0.02	0.92	0.01	0.00
3	0.01	0.02	0.03	0.00	0.03	0.89	0.02	0.00
4	0.03	0.02	0.03	0.00	0.03	0.84	0.03	0.01
5	0.04	0.03	0.04	0.01	0.02	0.80	0.05	0.01
6	0.05	0.03	0.04	0.01	0.02	0.76	0.08	0.02
7	0.05	0.03	0.04	0.02	0.02	0.72	0.10	0.02
8	0.06	0.03	0.04	0.03	0.02	0.67	0.12	0.03
9	0.06	0.03	0.04	0.04	0.02	0.63	0.15	0.04
10	0.06	0.03	0.04	0.05	0.02	0.59	0.17	0.04
11	0.06	0.04	0.04	0.06	0.02	0.55	0.19	0.05
12	0.06	0.04	0.04	0.07	0.02	0.51	0.21	0.06
13	0.06	0.04	0.04	0.08	0.03	0.48	0.22	0.06
14	0.05	0.04	0.04	0.09	0.03	0.45	0.23	0.07
15	0.05	0.04	0.04	0.10	0.03	0.43	0.24	0.07
16	0.05	0.05	0.04	0.11	0.03	0.42	0.24	0.08
17	0.05	0.05	0.04	0.11	0.03	0.41	0.24	0.08
18	0.05	0.05	0.04	0.11	0.03	0.41	0.23	0.08
19	0.05	0.05	0.03	0.11	0.04	0.42	0.22	0.08
20	0.05	0.05	0.03	0.11	0.04	0.43	0.21	0.08
21	0.05	0.05	0.03	0.10	0.04	0.45	0.20	0.07
22	0.06	0.05	0.03	0.10	0.04	0.47	0.19	0.07
23	0.07	0.05	0.03	0.09	0.04	0.48	0.18	0.06
24	0.07	0.05	0.03	0.09	0.04	0.50	0.17	0.06

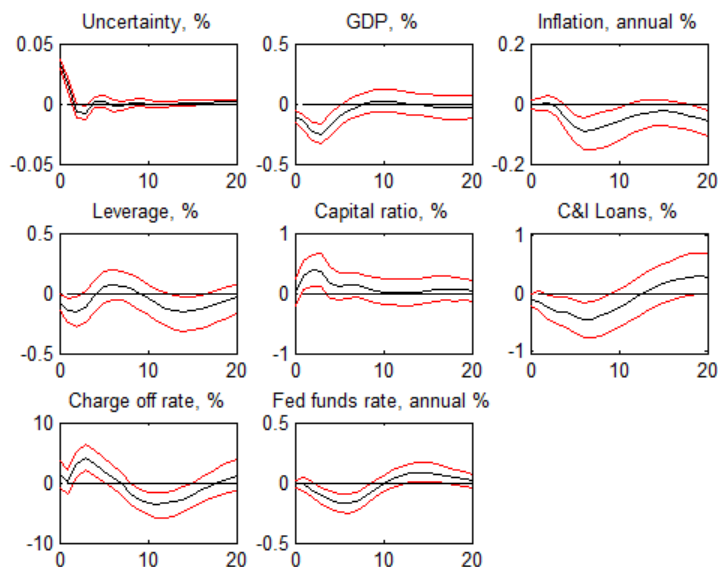
D. Impulse response functions to uncertainty shock, the extended model with commercial and industrial loans, uncertainty measure – conditional heteroskedasticity of GDP growth, 1985Q1-2007Q4.



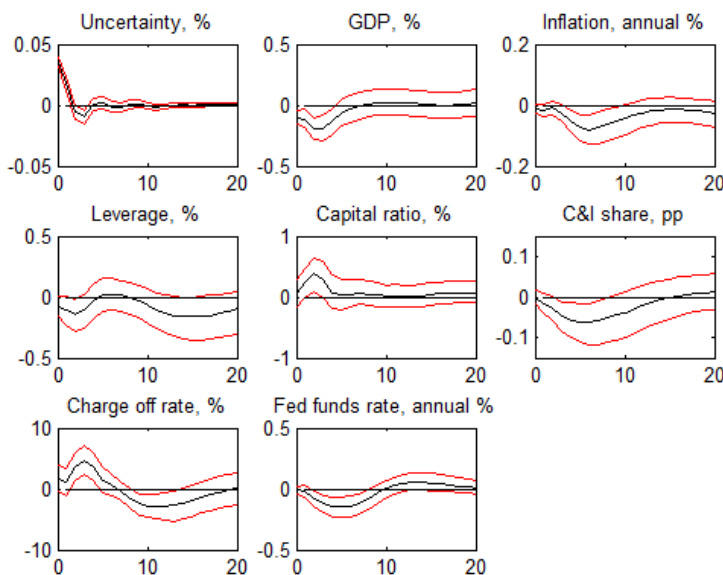
Note. The impulse responses are based on the benchmark specification: the federal funds rate is a monetary policy measure,  $X_{2t}$  is empty (all the variables are in  $X_{1t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). According to AIC, the VAR order includes two lags. Y axis units – percents, X axis units – quarters.

Figure 1.15: Impulse response functions, the extended model with commercial and industrial loans; uncertainty measure – cross-sectional standard deviation of firms' pretax profit growth

A. Impulse response functions to uncertainty shock, C&I loans in levels.



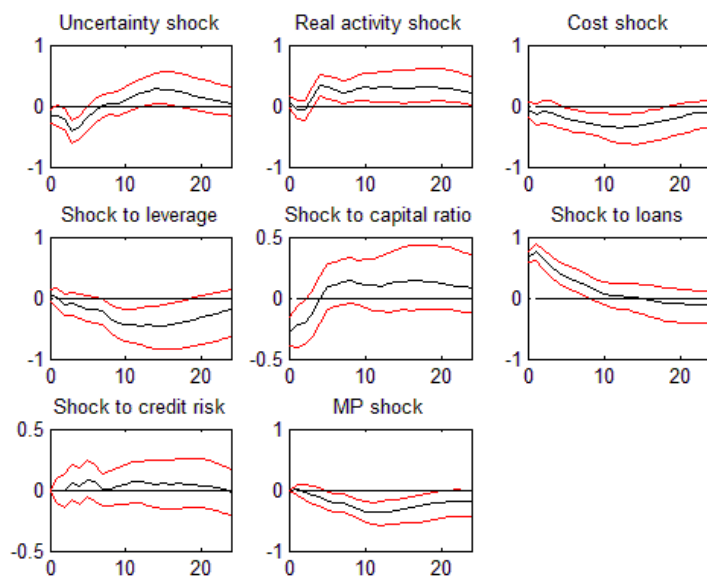
B. Impulse response functions to uncertainty shock, C&I loans as the share of the portfolio.



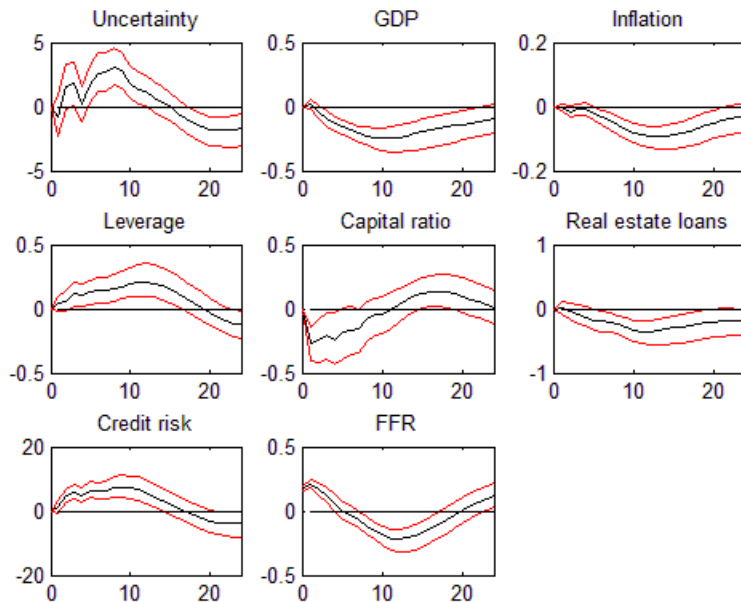
Note. The impulse responses are based on the benchmark specification: the federal funds rate is a monetary policy measure,  $X_{2t}$  is empty (all the variables are in  $X_{1t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). According to AIC, the VAR order includes two lags. X axis units – quarters.

Figure 1.16: Impulse response functions, the extended model with real estate loans, uncertainty measure – news-based uncertainty index

A. Responses of real estate loans to various shocks, in %.



B. Impulse response functions to monetary policy shock (monetary contraction), in %.



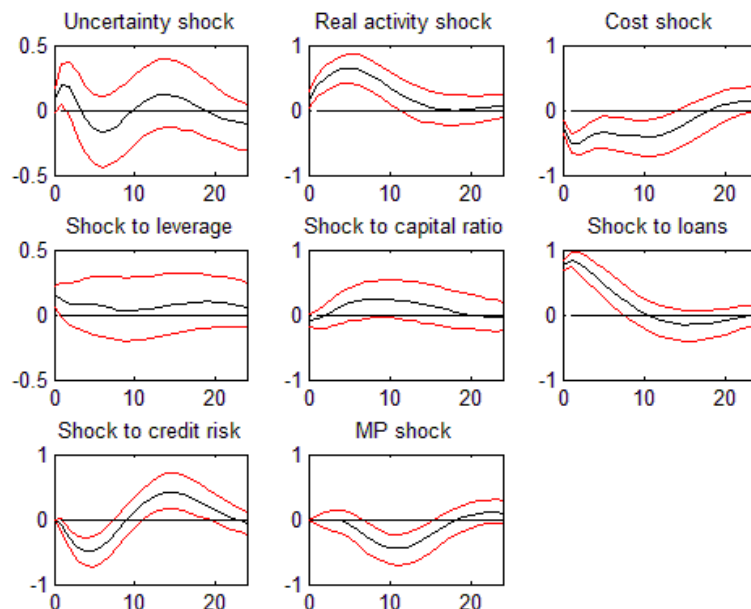
Note. The impulse responses are based on the benchmark specification: the federal funds rate is a monetary policy measure,  $X_{2t}$  is empty (all the variables are in  $X_{1t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). According to AIC, the VAR order includes four lags. Y axis units – percents, X axis units – quarters.

Table 1.9: Forecast error variance decomposition of real estate loans in the extended model, uncertainty measure – news-based uncertainty index

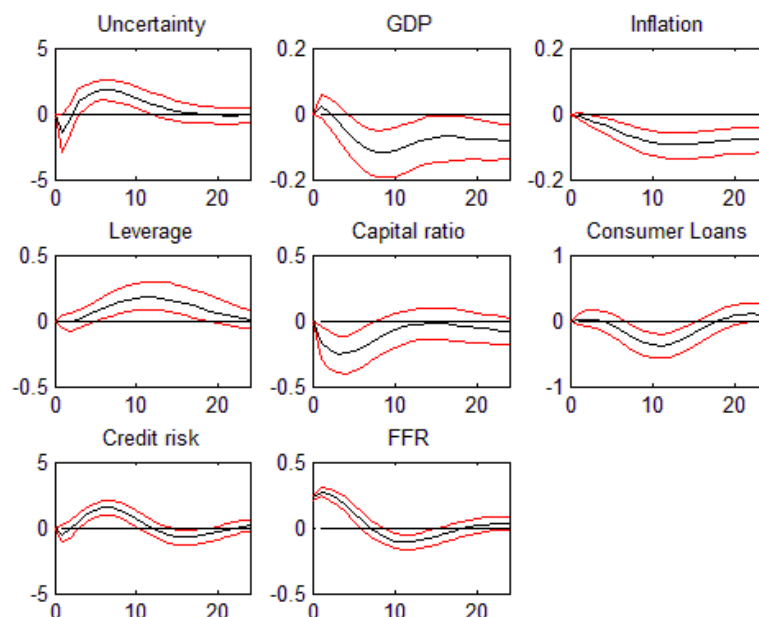
p/v	Unc	GDP	Infl	Levera	Cap ra	Real e	Ch off	FFR
1	0.05	0.01	0.01	0.00	0.14	0.80	0.00	0.00
2	0.04	0.01	0.01	0.00	0.11	0.82	0.00	0.00
3	0.05	0.01	0.02	0.00	0.11	0.81	0.00	0.00
4	0.10	0.01	0.02	0.00	0.10	0.76	0.00	0.00
5	0.12	0.03	0.03	0.00	0.09	0.72	0.00	0.00
6	0.12	0.05	0.04	0.01	0.08	0.69	0.00	0.01
7	0.11	0.06	0.06	0.01	0.07	0.66	0.00	0.02
8	0.10	0.07	0.08	0.02	0.06	0.63	0.00	0.03
9	0.09	0.08	0.10	0.04	0.06	0.59	0.00	0.04
10	0.08	0.09	0.12	0.06	0.06	0.53	0.00	0.06
11	0.07	0.09	0.14	0.09	0.05	0.47	0.00	0.08
12	0.07	0.10	0.15	0.12	0.05	0.41	0.00	0.10
13	0.07	0.10	0.17	0.14	0.05	0.36	0.00	0.12
14	0.06	0.10	0.18	0.17	0.05	0.31	0.00	0.13
15	0.07	0.10	0.19	0.19	0.05	0.27	0.00	0.14
16	0.07	0.09	0.20	0.21	0.05	0.24	0.00	0.14
17	0.07	0.09	0.20	0.22	0.05	0.21	0.00	0.15
18	0.07	0.09	0.20	0.24	0.05	0.19	0.00	0.15
19	0.07	0.09	0.20	0.25	0.06	0.17	0.00	0.15
20	0.07	0.09	0.20	0.26	0.06	0.16	0.00	0.15
21	0.07	0.09	0.20	0.27	0.06	0.15	0.00	0.15
22	0.07	0.10	0.20	0.28	0.06	0.14	0.00	0.15
23	0.06	0.10	0.20	0.29	0.07	0.14	0.00	0.15
24	0.06	0.10	0.19	0.29	0.07	0.13	0.00	0.15

Figure 1.17: Impulse response functions, the extended model with consumer loans, uncertainty measure – news-based uncertainty index

A. Responses of consumer loans to various shocks, in %.



B. Impulse response functions to monetary policy shock (monetary contraction), in %.



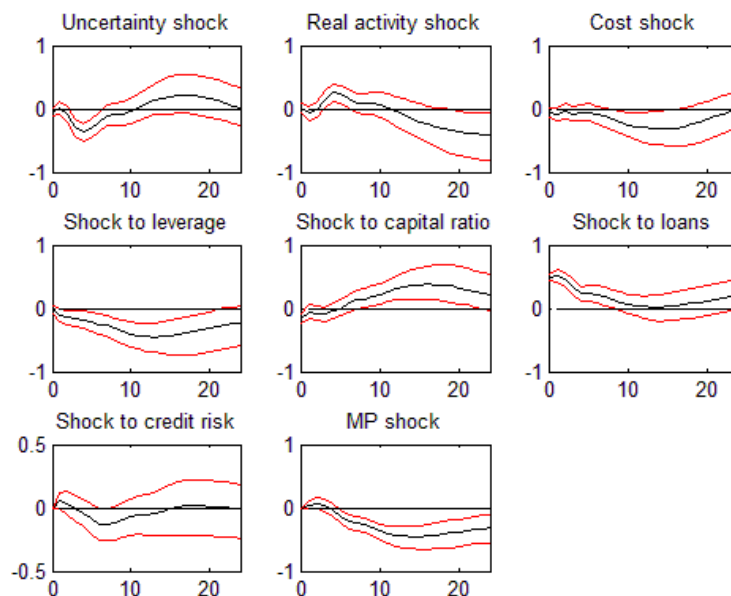
Note. The impulse responses are based on the benchmark specification: the federal funds rate is a monetary policy measure,  $X_{2t}$  is empty (all the variables are in  $X_{1t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). According to AIC, the VAR order includes two lags. Y axis units – percents, X axis units – quarters.

Table 1.10: Forecast error variance decomposition of real consumer loans in the extended model, uncertainty measure – news-based uncertainty index

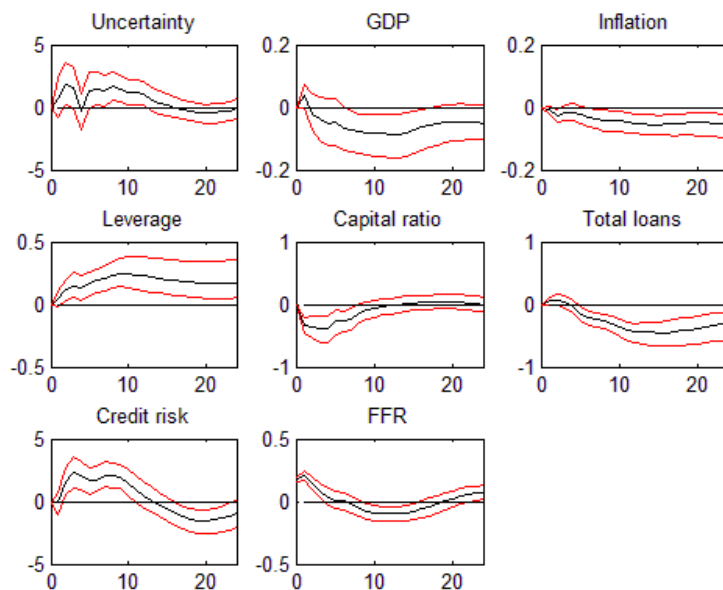
p/v	Unc	GDP	Infl	Levera	Cap ra	Cons l	Ch off	FFR
1	0.00	0.03	0.09	0.01	0.01	0.87	0.00	0.00
2	0.00	0.07	0.14	0.00	0.00	0.78	0.01	0.00
3	0.00	0.09	0.15	0.00	0.00	0.71	0.04	0.00
4	0.00	0.11	0.15	0.00	0.00	0.65	0.08	0.00
5	0.00	0.13	0.14	0.00	0.00	0.60	0.11	0.00
6	0.00	0.15	0.14	0.00	0.00	0.56	0.14	0.00
7	0.01	0.17	0.14	0.00	0.01	0.52	0.15	0.01
8	0.01	0.19	0.14	0.00	0.01	0.48	0.16	0.02
9	0.01	0.20	0.14	0.00	0.02	0.45	0.16	0.03
10	0.01	0.21	0.14	0.00	0.03	0.43	0.15	0.04
11	0.01	0.21	0.14	0.00	0.04	0.41	0.14	0.05
12	0.01	0.21	0.14	0.00	0.05	0.39	0.13	0.07
13	0.02	0.20	0.14	0.01	0.06	0.37	0.13	0.08
14	0.04	0.19	0.14	0.01	0.07	0.35	0.12	0.09
15	0.05	0.18	0.14	0.01	0.07	0.33	0.12	0.09
16	0.07	0.17	0.13	0.02	0.08	0.32	0.12	0.10
17	0.08	0.16	0.13	0.02	0.08	0.30	0.12	0.10
18	0.09	0.16	0.13	0.02	0.09	0.29	0.13	0.10
19	0.10	0.15	0.12	0.02	0.09	0.29	0.13	0.09
20	0.10	0.15	0.12	0.02	0.09	0.28	0.13	0.09
21	0.11	0.15	0.12	0.03	0.09	0.28	0.14	0.09
22	0.11	0.15	0.12	0.03	0.09	0.27	0.14	0.09
23	0.11	0.15	0.12	0.03	0.09	0.27	0.14	0.09
24	0.11	0.15	0.12	0.03	0.09	0.27	0.15	0.09

Figure 1.18: Impulse response functions, the extended model with total loans, uncertainty measure – news-based uncertainty index

A. Responses of total loans to various shocks, in %.



B. Impulse response functions to monetary policy shock (monetary contraction), in %.



Note. The impulse responses are based on the benchmark specification: the federal funds rate is a monetary policy measure,  $X_{2t}$  is empty (all the variables are in  $X_{1t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). According to AIC, the VAR order includes four lags. Y axis units – percents, X axis units – quarters.

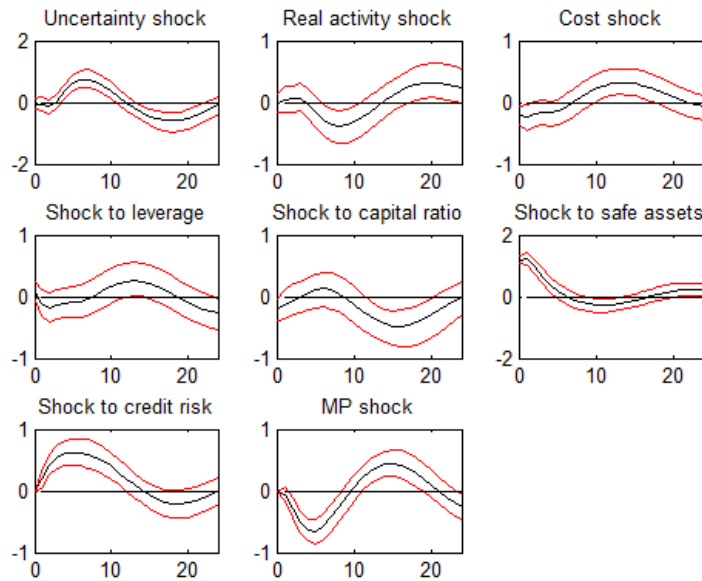


Table 1.11: Forecast error variance decomposition of total loans in the extended model, uncertainty measure – news-based uncertainty index

p/v	Unc	GDP	Infl	Levera	Cap ra	Total	Ch off	FFR
1	0.01	0.00	0.01	0.00	0.09	0.89	0.00	0.00
2	0.00	0.01	0.02	0.02	0.05	0.89	0.00	0.00
3	0.01	0.01	0.01	0.03	0.04	0.88	0.00	0.01
4	0.07	0.02	0.01	0.04	0.04	0.80	0.00	0.01
5	0.15	0.05	0.01	0.05	0.04	0.69	0.00	0.01
6	0.20	0.07	0.01	0.07	0.03	0.61	0.01	0.02
7	0.21	0.07	0.01	0.09	0.03	0.55	0.01	0.03
8	0.21	0.07	0.01	0.11	0.03	0.51	0.02	0.05
9	0.19	0.07	0.02	0.14	0.03	0.47	0.02	0.07
10	0.17	0.06	0.03	0.18	0.04	0.41	0.02	0.09
11	0.15	0.05	0.04	0.21	0.05	0.35	0.02	0.12
12	0.13	0.04	0.05	0.24	0.07	0.30	0.01	0.15
13	0.11	0.04	0.07	0.26	0.09	0.25	0.01	0.18
14	0.09	0.03	0.08	0.28	0.11	0.21	0.01	0.19
15	0.08	0.03	0.08	0.29	0.13	0.17	0.01	0.21
16	0.08	0.03	0.09	0.29	0.14	0.15	0.01	0.21
17	0.07	0.03	0.09	0.29	0.16	0.13	0.01	0.22
18	0.07	0.04	0.10	0.29	0.17	0.11	0.01	0.22
19	0.07	0.04	0.10	0.28	0.18	0.10	0.00	0.22
20	0.07	0.05	0.10	0.28	0.19	0.09	0.00	0.22
21	0.07	0.06	0.10	0.27	0.20	0.08	0.00	0.22
22	0.07	0.07	0.10	0.27	0.20	0.07	0.00	0.22
23	0.07	0.07	0.10	0.26	0.21	0.06	0.00	0.22
24	0.07	0.08	0.09	0.26	0.21	0.06	0.00	0.22

Figure 1.19: Impulse response functions, the extended model with safe assets, uncertainty measure – news-based uncertainty index

A. Responses of safe assets to various shocks, in %.



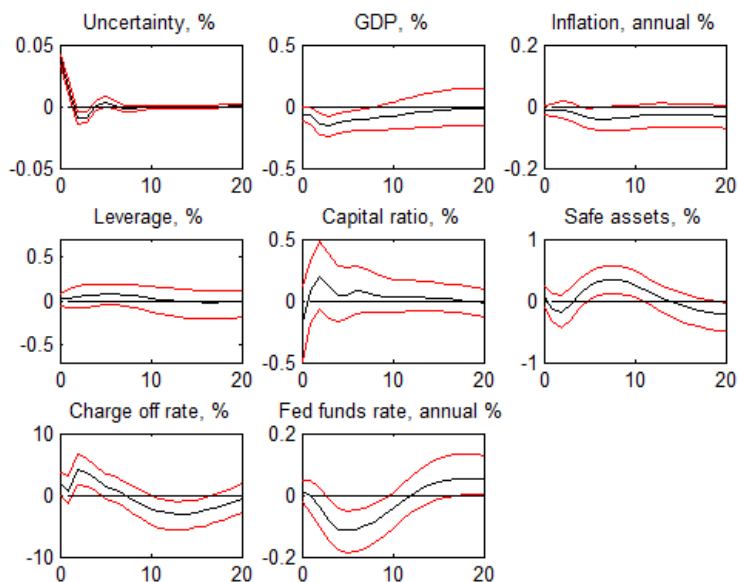
Note. The impulse responses are based on the benchmark specification: the federal funds rate is a monetary policy measure,  $X_{2t}$  is empty (all the variables are in  $X_{1t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). According to AIC, the VAR order includes two lags. Y axis units – percents, X axis units – quarters.

Table 1.12: Forecast error variance decomposition of safe assets in the extended model, uncertainty measure – news-based uncertainty index

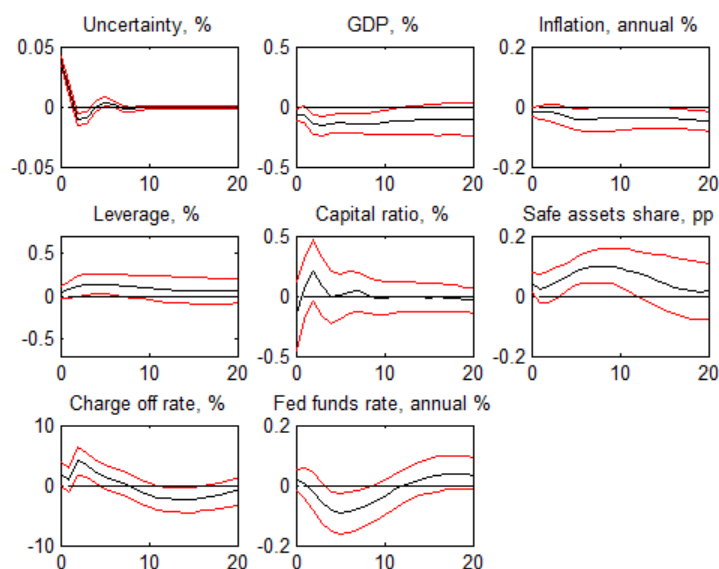
p/v	Unc	GDP	Infl	Levera	Cap ra	Safe a	Ch off	FFR
1	0.02	0.02	0.06	0.00	0.04	0.86	0.00	0.00
2	0.05	0.02	0.07	0.00	0.02	0.80	0.01	0.02
3	0.08	0.03	0.09	0.01	0.02	0.70	0.04	0.02
4	0.07	0.06	0.13	0.04	0.02	0.57	0.09	0.02
5	0.11	0.05	0.13	0.08	0.03	0.44	0.14	0.02
6	0.16	0.04	0.12	0.10	0.02	0.36	0.16	0.02
7	0.21	0.04	0.11	0.10	0.02	0.30	0.18	0.04
8	0.24	0.05	0.10	0.09	0.01	0.25	0.20	0.05
9	0.25	0.08	0.09	0.08	0.01	0.23	0.20	0.06
10	0.27	0.10	0.08	0.07	0.01	0.22	0.20	0.05
11	0.27	0.12	0.07	0.06	0.01	0.21	0.20	0.05
12	0.27	0.14	0.07	0.06	0.01	0.20	0.19	0.05
13	0.27	0.16	0.07	0.06	0.01	0.20	0.18	0.05
14	0.26	0.17	0.08	0.07	0.01	0.19	0.18	0.05
15	0.25	0.16	0.09	0.07	0.02	0.18	0.17	0.06
16	0.25	0.15	0.10	0.08	0.02	0.17	0.16	0.07
17	0.25	0.14	0.11	0.09	0.02	0.16	0.15	0.08
18	0.26	0.13	0.12	0.09	0.03	0.15	0.14	0.08
19	0.27	0.13	0.12	0.09	0.03	0.14	0.13	0.09
20	0.28	0.13	0.12	0.09	0.03	0.14	0.13	0.09
21	0.28	0.13	0.12	0.09	0.04	0.13	0.12	0.08
22	0.29	0.14	0.12	0.08	0.04	0.13	0.12	0.08
23	0.29	0.14	0.12	0.08	0.05	0.13	0.12	0.08
24	0.28	0.15	0.12	0.08	0.05	0.13	0.11	0.08

Figure 1.20: Impulse response functions to uncertainty shock, extended model with safe assets; uncertainty measure – cross-sectional standard deviation of firms' pretax profit growth

A. Safe assets variable in levels.



B. Safe assets variable as a share of total assets.



Note. The impulse responses are based on the benchmark specification: the federal funds rate is a monetary policy measure,  $X_{2t}$  is empty (all the variables are in  $X_{1t}$ ). 90% bias-corrected bootstrap confidence bands are calculated as in Kilian (1998). According to AIC, the VAR order includes two lags. Y axis units – percents, X axis units – quarters.

## Chapter 2

# Banks' assets, uncertainty and macroeconomy

### 2.1 Introduction

Being an important factor of slow economic recovery, weak growth of credit in the aftermath of the financial crisis of 2007-2009 has been a serious concern of policymakers. Despite highly accommodative stance of monetary policy and various policies to enhance credit supply and to support credit demand, near-zero or negative growth of bank lending has been experienced by many advanced economies for a number of years<sup>1</sup> (see Figures 2.4 and 2.5 in Appendix). Given that efficient credit allocation is one of the pillars of growth<sup>2</sup>, its weakness hinders the full and sustained economic recovery.

A number of recent studies demonstrated that uncertainty have played a prominent role in shaping credit market developments during the financial crisis of 2007-2009<sup>3</sup>. The previous chapter provides robust evidence showing that banks reallocate their portfolios of assets following uncertainty shocks by reducing issuance of loans and increasing holdings of safe assets - cash and Treasury and agency securities. Based on this finding and responding to calls for more sophisticated modeling of financial intermediaries due to their nontrivial role in the recent financial crisis, I build a general equilibrium model, introducing two features into the banking sector modelling. First, I use a firm-theoretical model of bank behaviour and model banks as optimizing their balance sheet structure by solving the portfolio problem, where banks choose to allocate their funds between risky lending to entrepreneurs and risk-free government bonds. Second, motivated by empirical evidence and along the lines of theoretical literature, I model banks as risk-averse agents<sup>4</sup>. In practice banks should hold

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<sup>1</sup>For details see IMF Global Financial Stability Report, October 2013).

<sup>2</sup>The importance of intermediation-growth nexus in data is studied by King and Levine (1993), Demirgüç-Kunt and Maksimovic (1998), Jayaratne and Strahan (1996), Carbo-Valverde, Rodriguez-Fernandez and Udell (2005) and Rousseau and Wachtel (1998, 2000), among others. Chretien and Lyonnet (2014) show that cutbacks in lending by commercial banks was the main reason for the contraction in the balance sheet of the overall financial system during the 2008-2009 financial crisis.

<sup>3</sup>See, for example, Stock and Watson (2012), Balke and Zeng (2013), Caldara et al. (2016), Baum et al. (2008) and Quagliariello (2008).

<sup>4</sup>Evidence suggesting concave preferences of banks are Ratti (1980), Bhaumik and Piesse (2001), Nishiyama

a sufficient level of capital to protect themselves from the risk of insolvency, what underpins their negative attitude to uncertainty about future profitability. Aksoy and Basso (2014) and Danielsson et al. (2011) show that in presence of the Value-at-Risk constraint banks behave like risk-averse agents. Assuming concave preferences allows uncertainty to play a non-trivial role in banks' portfolio allocation.

In the theoretical model suggested here, banking sector faces non-diversifiable credit risk. This risk emerges, because loans are subject to default and because lending rate on non-defaulted loans specified in the loan contract is non state-contingent on future outcomes. I modify the optimal debt contract structure proposed originally in Bernanke et al. (1999) to allow lending rates be non-contingent on realization of shocks, such that banks could obtain non-zero profits, when an ex-post rate of defaults on loans is different from the rate that was expected by banks ex-ante. Heightened idiosyncratic uncertainty - a greater cross-sectional dispersion of productivity, - increases the rate of entrepreneurial defaults, and banks respond by increasing risk premium. Importantly, precautionary mechanism is in play: risk-averse banks charge lending rate, which in addition to remunerating for the increased expected defaults, provides self-insurance from profitability reduction. Thereby banks' expectations about their future profitability play key role in driving the endogenous movements of credit spread. In this respect the amplification mechanism in my model is in line with the one in Aksoy and Basso (2014), where term spreads' variations are brought about by expectations of banks of their future profitability<sup>5</sup>. Due to increasing external finance premium, the demand for loans falls. The asset portfolios of banks are reallocated: the share of risky lending goes down, while the share of risk-free assets (government bonds), acting as a buffer stock, goes up.

The simulations of the general equilibrium model reproduce a pattern, specified by a key postulate of the modern portfolio theory - that choices of an agent with concave preferences are characterized by a positive premium to the amount that she is willing to pay to avoid a fair gamble. Importantly, there are significant differences in the ways how this result is obtained in the modern portfolio theory and in the model suggested here. First, in my case risk is not measured by the variance of distribution of returns, as it is done commonly in the modern portfolio approach<sup>6</sup>. Instead, in the model here risk is a downside measure, specifically, it is a probability that idiosyncratic productivity of a borrower is lower than the one that allows her to pay back the loan (a borrower who cannot pay back the loan declares default). The size of credit risk, that the bank is prone to, is determined endogenously and follows from the structure of the optimal debt contract between banks and entrepreneurs. Second, I don't employ a quadratic utility function, which is conventionally used in the modern portfolio theory to analyze the problem of portfolio allocation of the risk-averse investor and to

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(2007) and Raju (2014), among others. Theoretical papers employing an analogous assumption are, for example, Parkin (1970), Pyle (1971), Ross (1973), Hart and Jaffee (1974), Koehn and Santomero (1980), Morrison (2000) and Greenwald and Stiglitz (1990).

<sup>5</sup>Aksoy and Basso (2014) also provide empirical evidence that corroborates the link between expected bank profitability and term spreads movements.

<sup>6</sup>There is a growing amount of works, however, where risk is characterized by a downside measure. See, for example, Chaigneau and Eeckhoudt (2016).

demonstrate how concavity of investor's preferences affects the optimal choice of the fraction of portfolio invested in the risky asset. I assume a constant relative risk aversion type of utility function for banks. Third, risk-free rate in the suggested model is unknown ex-ante, in contrast to it being known in advance in the modern portfolio theory; additionally, it is determined endogenously, responding to the movements of output and inflation according to the Taylor rule.

Uncertainty has received a substantial attention as a factor that exerts an important impact on economic developments during the Great Recession. Stock and Watson (2013) argue that the decline of output and employment in the Great Recession was mainly due to financial and uncertainty shocks. Recent empirical macro- and microeconomic research documents strong negative relationship between uncertainty and growth. This is demonstrated, for example, in cross-country studies of Ramey and Ramey (1995) and Engle and Rangel (2008). A VAR approach is used by Bloom (2009) to show that there is a drop and rebound of industrial production following the impact of uncertainty shock. By estimating a fully fledged DSGE model, Justiniano and Primiceri (2008) demonstrate that decline in the volatility of output in the mid-1980s happened due to change in volatility of various types of technology shocks<sup>7</sup>. Additionally, Aastveit et al. (2013) and Bloom et al. (2012) show that increased uncertainty weakens the effectiveness of monetary policy. As for microeconomic evidence, significant negative effect of uncertainty on investment in the firm-level panel data is shown by Leahy and Whited (1996). Guiso and Parigi (1999) document the negative impact of uncertainty on firms' expectations of demand. Bloom, Bond and van Reenen (2007) demonstrate that uncertainty gives rise to the "caution effect", while Panousi and Papanikolaou (2012) show that negative effect of uncertainty appears to be management risk-aversion. To sum up, uncertainty is demonstrated to be an important factor that drives the dynamics of economy at both macro and micro levels.

In existing literature some papers analyze the effects of heightened uncertainty about total factor productivity<sup>8</sup>, while other works investigate the impact of shocks to idiosyncratic productivity of firms<sup>9</sup>. I contribute to this literature by evaluating the impact that idiosyncratic uncertainty makes on the portfolio reallocation of the banking sector and the resulting general equilibrium macroeconomic effects. The uncertainty is modelled as a time-varying volatility of idiosyncratic productivity component of entrepreneurs, so that in times of heightened uncertainty the probability of the events on the tails of the distribution of entrepreneurial productivity is higher. This implies not only increased credit risk, what induces risk-neutral banks to charge a higher risk premium to compensate for the greater possible losses, but also greater uncertainty about the future bank profitability, what makes

<sup>7</sup>Among other papers, showing that uncertainty shocks produce economic contractions are Bachmann et al. (2013), Alexopoulos and Cohen (2009), Bachmann and Bayer (2011) and Knotek and Khan (2011).

<sup>8</sup>See, for example, Fernandez-Villaverde and Rubio-Ramirez (2007), Justiniano and Primiceri (2008), Fernandez-Villaverde et al. (2011), Basu and Bundick (2012), Bloom et al. (2012), among others.

<sup>9</sup>Bloom et al. (2012), Christiano et al. (2013) and Bachmann and Bayer (2011) study the effect of changing volatility of cross-sectional dispersion of firm-level productivity. The relative importance of aggregate and idiosyncratic uncertainty, which are sometimes referred to as macro and micro uncertainty, is studied in Balke et al. (2012) and Cesa-Bianchi and Fernandez-Corugedo (2014).

risk-averse banks increase risk premium further to self-insure against profitability reduction. I find that the proposed mechanism of precautionary motive of risk-averse banks produces significant portfolio reallocation effects, it helps to explain an additional portion of the risky lending reduction and business cycle movements.

Another stream of literature, related to my work, explores the role of credit frictions as a factor that contributes to business cycle fluctuations. Despite employing different workhorse models with various types of frictions, the key studies in this literature - Bernanke et al. (1999), Holmstrom and Tirole (1997), Kiyotaki and Moore (1997) and Carlstrom and Fuerst (1997), - agree that financial frictions have significant effects on movement of aggregates. They don't only make an impact as amplifying the effect of exogenous shocks<sup>10</sup>, but also act as a source of disturbances that play an important role for business cycles<sup>11</sup>. The recent and growing literature analyses the role of credit market imperfections in amplifying the effect of uncertainty. Among those, Arellano et al. (2012) demonstrate that higher uncertainty is a factor that reduces factor inputs of firms and their output, when firms are subject to costly default. Christiano et al. (2013) and Gilchrist et al. (2013) show that idiosyncratic uncertainty shocks increase the external financial premium in presence of asymmetric information in lending relationships. Benes and Kumhof (2015) also analyze the general equilibrium model with financial accelerator and endogenous risky lending; they focus on bank capital adequacy requirements and demonstrate that countercyclical capital buffers increase welfare. Bonciani and van Rye (2013) show that stickiness of banking retail interest rates amplifies the effect of TFP uncertainty on economy. Balke and Zeng (2013) show that the financial crisis of 2007-2009 was mostly due to decline in financial intermediation that originated from output and uncertainty shocks.

I contribute to the literature on credit frictions by showing that in the financial accelerator framework a la Bernanke et al. (1999), where lenders are risk-averse and choose their balance sheets volumes before observing shock values, heightened idiosyncratic uncertainty leads, first, to widening of credit spread, and second, to lowering of the volume of bank credit. I demonstrate that allowing for concave preferences of banks gives rise to the precautionary savings motive, such that assets portfolios of banks are reallocated, what is consistent with my empirical results presented in chapter 1. I show that financial accelerator mechanism works to amplify these effects, as the reduced demand for capital from entrepreneurs induces price of capital to go down, such that entrepreneurial net worth decreases, implying even higher risk premium charged by banks and the further reduction of bank credit.

## 2.2 Uncertainty and risk-averse banking sector

This section provides intuition for the dynamics of bank portfolio obtained in the general equilibrium setup of the model in this chapter below. It introduces the idea of bank's pre-

<sup>10</sup>See, for example, Gertler and Karadi (2011) and Balke (2000) on this.

<sup>11</sup>For example, Christiano et al. (2010) distinguishes between a banking technology shock and a bank reserve demand shock, which have consequential effects on movements of total output. Hafstead and Smith (2012) examine the role of a shock to bank-specific loan productivity or a shock to the cost of bank intermediation).



cautionary motive when there is uncertainty about bank future profitability.

Consider a case with a representative risk-averse bank in economy. The bank funds its activity by issuing deposits for households  $D_t$  and allocates its funds to corporate loans  $L_t$  and riskless government bonds  $B_t$ . Issuing loans is risky and yields higher return than the return on government bonds: risk premium compensates for risk of issuing loans. Bank's stylized balance sheet constraint is:

$$D_t = L_t + B_t, \quad (2.1)$$

and the profits of the bank are:

$$\mathbb{E}_t(\pi_{t+1}) = (r_t^l L_t) v_t + r_t^g B_t - r_t^d D_t, \quad (2.2)$$

where  $r_t^l$  is the bank's lending rate,  $r_t^g$  is risk-free rate on government bonds,  $r_t^d$  is rate on deposits and  $v_t$  is the share of non-defaulted loans<sup>12</sup>.

Under the assumption of bank being risk-neutral the no-arbitrage condition implies that deposit rate coincides with risk-free rate, and risk spread is accounted by default rate on loans, while bank gets no profit:

$$r_t^d = r_t^g = r_t^l * v_t. \quad (2.3)$$

In this case bank would satisfy all the demand for loans and deposits adjusting the volume of government bonds held on its balance sheet.

Instead of risk-neutrality let's assume that bank's preferences are represented with utility function  $u(\cdot)$  featuring risk-prudence, following the definition of prudence from Kimball (1990):  $u'(\cdot) > 0$ ,  $u''(\cdot) < 0$  and  $u'''(\cdot) > 0$ <sup>13</sup>. Then the portfolio problem of the bank is:

$$\max_{L_t, B_t, D_t} E(u(\pi_{t+1})) \quad s.t.(2.1) \quad (2.4)$$

The optimizing behaviour of a risk-averse bank is different from that of a risk-neutral one. In maximizing its expected utility, risk-averse bank takes into account the stochastic nature of the share of non-defaulted firms  $v_t$ <sup>14</sup>. Ultimately,  $v_t$  could depend on stochastic properties of idiosyncratic return to capital (including its time-varying volatility that I refer to as idiosyncratic uncertainty) or/and on stochastic properties of the aggregate productivity process.

To examine the impact of uncertainty on bank's choice of risky and safe assets share in its portfolio, consider that increased uncertainty induces banks to take into account a wider range of possible values of future profits around  $E(\pi_{t+1})$ : from the lowest possible  $\pi_{t+1}^L$  to

<sup>12</sup>Throughout the chapter all the interest rates are gross rates. Lower case letters denote nominal interest rates and upper case letters denote real interest rates.

<sup>13</sup>The terms risk-averse and risk-prudent are used interchangeably here.

<sup>14</sup>In the general equilibrium setup of the model this share is endogenous: it is a function of the equilibrium threshold level of idiosyncratic productivity shock that separates bankrupt and non-bankrupt entrepreneurs. This cut-off value is a solution of the entrepreneurial maximization problem. See the Optimal Debt Contract section for details.

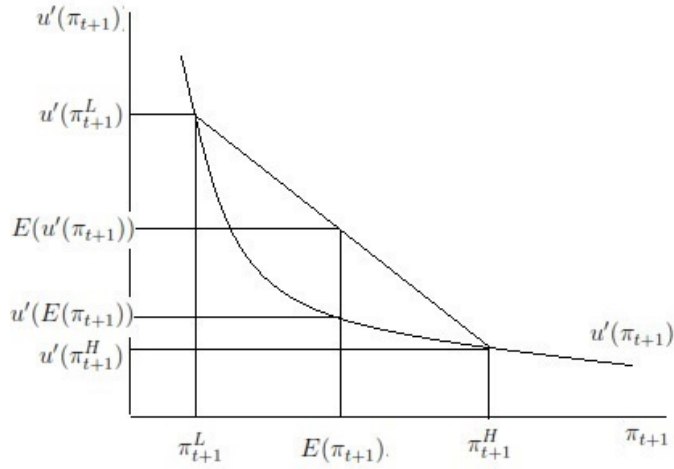


Figure 2.1: Impact of uncertainty on expected profit of a bank

the highest possible  $\pi_{t+1}^H$  (see Figure 2.1). Because the function of marginal profit  $u'(\pi_{t+1})$  is convex ( $u'''(\cdot) > 0$ ), Jensen inequality implies  $E(u'(\pi_{t+1})) > u'(E(\pi_{t+1}))$ . Thus, when there is uncertainty about future returns, expected marginal utility is higher than in the case of no uncertainty. Higher expected marginal utility of profit in period  $t + 1$  requires lower level of profit  $\pi_{t+1}$ , what is attained by changing the structure of its portfolio: issuing less risky loans  $L_t$ , which pay higher return, and increasing the holdings of safe low-yield government bonds  $B_t$ . Hence, the effect of heightened uncertainty on the portfolio of risk-averse bank is a greater share of safe assets; risk-averse banks smooth out their profit across states of nature by increasing their riskless bonds holding motivated by precautionary considerations. Specifically, they choose to ensure the relative stability of the profit aiming at avoiding the possible realisation of critically high level of defaults.

### 2.3 The general equilibrium model

The theoretical model suggested in this chapter is a general equilibrium model based on the costly state verification setup and the financial accelerator mechanism drawn from Bernanke et al. (1999) with risk-averse portfolio optimizing banking sector and non-diversifiable credit risk. I endogenize bank credit spread and analyze the impact of idiosyncratic uncertainty shocks on portfolio reallocation of the banking sector and macroeconomic outcomes. The model economy is populated with households, entrepreneurs, banks, capital goods producers, final good producers, the government and a monetary policy authority. Households consume, supply labour and save via bank deposits. Entrepreneurs produce intermediate goods using capital, financed either internally from the net worth or externally by borrowing funds from the banks. The banking sector allocates deposits raised from households to risky loans and risk-free bonds. Capital goods producers sell capital, that they create, to entrepreneurs. Final good producers resell intermediate goods, produced by entrepreneurs,

with a markup. The government issues riskless bonds and buys the final good. The central bank implements monetary policy.

### 2.3.1 Banking sector

There is a representative bank in economy owned by households, that provides loans to entrepreneurs and funds its investments by households' deposits. The bank also buys government bonds that pay risk-free rate. At time  $t$  the balance sheet of the bank is:

$$D_t = L_t + B_t, \quad (2.5)$$

where current period deposits  $D_t$  constitute liabilities, and loans  $L_t$  issued for entrepreneurs and risk-free government bonds  $B_t$  purchased today comprise asset side of the balance sheet. At the end of period  $t$  the bank chooses how to allocate its funds in portfolio of assets, which will generate the return in period  $t + 1$ :  $L_t$  and  $B_t$  are chosen at time  $t$ , i.e. the timing of bank assets corresponds to the time, when the loans are issued and bonds are purchased and not when the payoff occurs. A specialized loan branch within the bank issues loans for entrepreneurs and performs the monitoring of loans function<sup>15</sup>. It receives  $L_t$  from its parent branch at period  $t$  and commits to pay back non-state contingent nominal interest rate  $r_t^e$ , set by the parent branch at time  $t + 1$ . The allocation of assets between lending and safe assets holding is decided by the parent branch.

The expected profit of the banking sector  $\Pi_{t+1}$  is the difference between its expected income and expenses, where incomes comprise the principal and interest on non-defaulted loans, the assets of defaulted entrepreneurs less the costs of monitoring them and the principal and interest on government bonds, while expenses paid include the principal and interest on deposits issued to households in period  $t$ :

$$\mathbb{E}_t \Pi_{t+1} = \mathbb{E}_t [(1 - F(\bar{\omega}_{t+1})) r_t^L L_t + (1 - \mu) V_{t+1}^d + r_t^G B_t - r_t^D D_t] \quad (2.6)$$

where  $(1 - F(\bar{\omega}_{t+1}))$  is the ex-post share of non-defaulted borrowers,  $r_t^L$  is lending rate for loans issued at time  $t$ ,  $(1 - \mu) V_{t+1}^d$  is the value of assets of defaulted firms took over by the bank after paying the monitoring costs  $\mu$ ,  $r_t^D D_t$  is bank's payment for households' deposits issued at  $t$  and  $r_t^G B_t$  is the return on government bonds purchased at  $t$ . Bank profit  $\Pi_{t+1}$  is transferred lump-sum to households at the end of period  $t + 1$ .

I assume concave preferences of the banking sector. First, there is multiple evidence demonstrating that banks act as risk-averse agents in empirical literature. This is shown, for example, in Ratti (1980), Bhaumik and Piesse (2001), Nishiyama (2007) and Raju (2014). Additionally, some papers demonstrate that the choices of bank managers reveal their risk-averse type of preferences<sup>16</sup>. Second, the assumption of concavity of bank preferences is a

<sup>15</sup>I use this assumption following Christiano et al. (2010).

<sup>16</sup>Evidence of bank managers' risk-aversion is presented, for instance, in Flannery (1989), Hughes and Mester (1998), Pecchenino (1998) and Panousi and Papanikolaou (2012).

commone one in theoretical literature on financial intermediation<sup>17</sup>. Third, the use of this assumption could be justified by the fact that in practice banks should hold a sufficient level of capital to protect themselves from the risk on insolvency. As a result, banks are non-neutral to uncertainty about future payoffs on loans and profitability, instead, they have negative attitude to this uncertainty. Aksoy and Basso (2014) and Danielsson et al. (2011) show that in presence of the Value-at-Risk constraint<sup>18</sup> banks behave like risk-averse agents. In particular, they show that Lagrange multiplier associated with the capital constraint enters into the banks' lending decisions just like a risk-aversion parameter, and as a result, adopting the risk-aversiness assumption is isomorphic to modelling risk-neutrality of risk-constrained banks. The aforementioned considerations support the use of assumption of concavity of bank preferences that I employ here.

I assume constant relative risk aversion (CRRA) type of utility function. The flow of utility is separable across periods and takes the form:

$$u(\Pi_t) = \frac{(\Pi_t)^{1-\kappa}}{1-\kappa}. \quad (2.7)$$

At time  $t$  the management of the parent branch of the bank chooses the share of the portfolio, to be invested in risky loans  $\alpha_t = \frac{L_t}{D_t}$ , to maximize its expected utility, taking into account the balance sheet constraint and taking as given interest rates on deposits, loans and risk-free bonds:

$$\max_{\alpha_t} \mathbb{E}_t \sum_{s=0}^{\infty} S_{t,t+s+1} u(\Pi_{t+s+1}), \quad (2.8)$$

where  $S_{t,t+1} = \beta \frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma} \pi_{t+1}}$  is the households' stochastic discount factor. Because both deposit rate and rate on government bonds are riskless, I use a simplifying assumption that  $r_t^G = r_t^D$  in each period, and rearrange the expression for bank profit (2.6) (see Technical appendix for details) and obtain:

$$\mathbb{E}_t \Pi_{t+1} = \mathbb{E}_t [L_t ((1 - F(\bar{\omega}_{t+1})) r_t^L - r_t^G) + (1 - \mu) V_{t+1}^d]. \quad (2.9)$$

The first order condition of the bank problem is (details can be found in the Technical appendix to this chapter):

$$\mathbb{E}_t [\Pi_{t+1}^{-\kappa} (r_t^{L,RA} (1 - F(\bar{\omega}_{t+1})) - r_t^G)] = 0, \quad (2.10)$$

where  $r_t^{L,RA}$  stands for the lending rate charged by a risk-averse bank.

To emphasize, the decision about the share of risky loans in portfolio  $\alpha_t$  is made at time  $t$  (accordingly, interest rate on loans  $r_t^L$  is set at  $t$ ), while the expected value of future profitabil-

<sup>17</sup>See, for example, Parkin (1970), Pyle (1971), Hart and Jaffee (1974), Koehn and Santomero (1980), Freixas and Rochet (2008) and Matthews and Thompson (2008).

<sup>18</sup>VaR constraint is a quantile measure of losses distribution, which limits the probability of portfolio losses. It states that losses of bank portfolio should not exceed the value of its net worth  $NW_t$ , thus, ensuring solvency of the bank with probability  $(1 - \alpha)$ :  $VaR_\alpha(Loss_t) \leq NW_t$ . Importance of accounting for VaR constraint has been emphasized, for example, by Adrian and Shin (2013).

ity at  $t + 1$  is taken into account. In contrast, risk-neutral banks, who are profit maximizers, have linear preferences about their future profit. Hence, the optimality condition assuming banks' risk-neutrality is:

$$r_t^{L,RN} \mathbb{E}_t[(1 - F(\bar{\omega}_{t+1}))] = r_t^G, \quad (2.11)$$

where  $r_t^{L,RN}$  stands for the lending rate charged by a risk-neutral bank.

As seen from (2.10) and (2.11), both types of banks charge lending rates, which are set to compensate for the risk of defaults on entrepreneurial loans  $F(\bar{\omega}_{t+1})$ . The difference is that banks with concave preferences also take into account the expected value of their future profitability, specifically, the marginal utility of future profit. By using the fact that  $r_t^L$  becomes known at  $t$  and applying the definition of covariance and the linearity property of expectations to (2.53), I expand this optimality condition to

$$r_t^{L,RA} \left[ \frac{Cov(\Pi_{t+1}^{-\kappa}, (1 - F(\bar{\omega}_{t+1})))}{\mathbb{E}_t[\Pi_{t+1}^{-\kappa}]} + \mathbb{E}_t[(1 - F(\bar{\omega}_{t+1}))] \right] = r_t^G. \quad (2.12)$$

By comparing (2.11) and (2.12), one can see that the difference between lending rates  $r_t^{L,RN}$  and  $r_t^{L,RA}$  depends on the sign of covariance  $Cov(\Pi_{t+1}^{-\kappa}, (1 - F(\bar{\omega}_{t+1})))$  in the left hand side of (2.12). Given that the share of non-defaulted entrepreneurs is correlated with bank profitability positively, its correlation with the marginal utility of profit is negative due to assumption of bank preferences' concavity. Hence,  $Cov(\Pi_{t+1}^{-\kappa}, (1 - F(\bar{\omega}_{t+1}))) < 0$ . The negative covariance in (2.12) decreases the multiplier of  $r_t^{L,RA}$  in the left hand side of (2.12) comparing to the multiplier of  $r_t^{L,RN}$  in the left hand side of (2.11). Therefore, under equal risk-free rates and under the same expected rate of entrepreneurial defaults, the lending rate charged by risk-averse banks exceeds the one charged by risk-neutral banks  $r_t^{L,RA} > r_t^{L,RN}$ .

The difference in risk premia charged by risk-neutral and risk-averse banks is explained by the precautionary mechanism: in view of heightened uncertainty risk-averse banks insure themselves from future profitability reduction anticipating increasing defaults. They increase risk premium today to diminish profitability reduction tomorrow that could arise due to elevated uncertainty. Banks' expectations about their future profitability play a key role in driving the endogenous movements of credit spread in my model. This link between bank spreads and their expected profitability was shown first in Aksoy and Basso (2014) to deliver endogenous movements in term spreads' variations; they also provide empirical evidence to corroborate it.

To show the effect of default risk and expected profitability on risk premium, I manipulate the optimality condition for risk-averse banks (2.12) to obtain (see Technical appendix for details)

$$RP_t^{RA} = \frac{1 - \frac{Cov(\Pi_{t+1}^{-\kappa}, (1 - F(\bar{\omega}_{t+1})))}{\mathbb{E}_t[\Pi_{t+1}^{-\kappa}]} - \mathbb{E}_t[(1 - F(\bar{\omega}_{t+1}))]}{\frac{Cov(\Pi_{t+1}^{-\kappa}, (1 - F(\bar{\omega}_{t+1})))}{\mathbb{E}_t[\Pi_{t+1}^{-\kappa}]} + \mathbb{E}_t[(1 - F(\bar{\omega}_{t+1}))]} r_t^G. \quad (2.13)$$

The risk premium charged by risk-neutral banks is:

$$RP_t^{RN} = \frac{1 - \mathbb{E}_t[(1 - F(\bar{\omega}_{t+1}))]}{\mathbb{E}_t[(1 - F(\bar{\omega}_{t+1}))]} r_t^G. \quad (2.14)$$

One can see that both risk premia are increasing in the expected risk of default:

$$\frac{\partial RP_t^{RA}}{\partial \mathbb{E}_t[F(\bar{\omega}_{t+1})]} > 0, \frac{\partial RP_t^{RN}}{\partial \mathbb{E}_t[F(\bar{\omega}_{t+1})]} > 0 \quad (2.15)$$

Additionally, risk premium of the risk-averse banking sector  $RP_t^{RA}$  features two properties. First, it decreases in expected bank profitability:

$$\frac{\partial RP_t^{RA}}{\partial \mathbb{E}_t[\Pi_{t+1}]} < 0. \quad (2.16)$$

Second, it increases in tightness of connection between profits and the rate of loans repayment:

$$\frac{\partial RP_t^{RA}}{\partial Cov(\Pi_{t+1}, (1 - F(\bar{\omega}_{t+1})))} > 0, \quad (2.17)$$

i.e. the more risk-averse bank relies on loans' repayment as a source of profit (in contrast to relying on assets of defaulted entrepreneurs), the higher risk premium it charges. These last two channels constitute the precautionary mechanism that characterizes the choices of risk-averse bank and induces lending rate charged by risk-averse to exceed the rate charged by risk-neutral one.

Notably, the analytical result of this section is in line with the conclusions of the modern portfolio theory that are derived under different assumptions. First, in the model here risk is not measured by the variance of distribution of returns, as it is done commonly in the modern portfolio approach. Instead, risk is a downside measure - a probability that idiosyncratic productivity of a borrower is lower than the one that allows her to pay back the loan. Second, I don't employ a quadratic utility function, which is conventionally used in the modern portfolio theory, but a constant relative risk aversion type of utility function for banks.

Another consideration worth noting is a distinct nature of the eminent precautionary saving mechanism, which arises in the households' consumption-saving problem, and the precautionary motive at work suggested here. In particular, the precautionary saving is brought about by higher variance of exogenous shock to household income, which increases the optimal choice of saving, if marginal utility is convex<sup>19</sup>. Instead here a positive shock to the variance of idiosyncratic entrepreneurial productivity component increases the optimal value of lending rate charged on loans by banks, when their preferences feature concavity.

<sup>19</sup>I follow the formulation of the precautionary saving mechanism along the lines of Rothschild and Stiglitz (1971) and Kimball (1990).

### 2.3.2 Households

A representative household chooses consumption  $C_t$ , total labour supply  $H_t^h$  and bank deposits  $D_t$  to maximize its expected discounted lifetime utility

$$\max_{C_t, H_t, D_t} \mathbb{E}_t \sum_{k=0}^{\infty} \beta^k [\ln(C_{t+k}) + \xi \ln(1 - H_{t+k}^h)] \quad (2.18)$$

subject to budget constraint

$$P_t C_t + D_t \leq W_t H_t^h + \Pi_t + r_{t-1}^D D_{t-1}, \quad (2.19)$$

where  $P_t$  is aggregate price level,  $W_t$  is nominal wage,  $\Pi_t$  is the profit of banks paid out to households, who own the banks as dividends, and  $r_{t-1}^D D_{t-1}$  is the nominal return on savings deposits issued in  $t - 1$ .

The first-order conditions for consumption, labour and deposits are:

$$C_t^{-1} = \beta \mathbb{E}_t [C_{t+1}^{-1} r_t^D \pi_{t+1}^{-1}], \quad (2.20)$$

$$\xi \frac{1}{1 - H_t^h} = C_t^{-1} W_t / P_t, \quad (2.21)$$

where the first one is Euler equation for real consumption, and the second one is intratemporal condition that determines tradeoff between real consumption and leisure. Stochastic discount factor of a representative household is defined as

$$SDF_{t,t+1} = \beta \mathbb{E}_t \frac{C_{t+1}^{-1}}{C_t^{-1} \pi_{t+1}}. \quad (2.22)$$

### 2.3.3 Entrepreneurs

Entrepreneurs are producers of the wholesale output  $Y_t$ . They live for a finite number of periods and are risk-neutral; in each period a probability of survival  $\gamma$  is constant. Entrepreneurs combine capital  $K_t$ , purchased in period  $t - 1$ , with labour  $H_t$  hired in  $t$  to produce wholesale output in the period  $t$ . Production function is assumed to be constant returns to scale, what enables using it as an aggregate relationship, rather than focusing on production function of each entrepreneur:

$$Y_t = A_t K_t^\alpha H_t^{1-\alpha}, \quad (2.23)$$

where  $A_t$  is an exogenous parameter of aggregate productivity.

Following Bernanke et al. (1999) and Carlstrom and Fuerst (1997), it is assumed that entrepreneurs supply labour in the general labour market to supplement their income. This assumption is made for a technical reason, in order for new and bankrupt entrepreneurs to have some net worth that allows them to start operations. Total labour input, used in the wholesale good production, is a composite of labour, supplied by entrepreneurs  $H_t^e$ , and the

household labour supply  $H_t^h$ .<sup>20</sup>

$$H_t = (H_t^e)^{1-\Omega} (H_t^h)^\Omega. \quad (2.24)$$

Net worth of entrepreneurs is composed of entrepreneurial equity  $V_t$  - the wealth gained by operating the firm, - and of entrepreneurial wage  $w_t^e$ . At the end of period  $t$  aggregate entrepreneurial net worth  $NW_{t+1}$  is

$$NW_{t+1} = \gamma V_t + w_t^e, \quad (2.25)$$

where  $\gamma V_t$  is time  $t$  equity value of entrepreneurs, who survive. Those entrepreneurs, who don't survive, consume their equity:  $C_t^e = (1 - \gamma) V_t$ .

Entrepreneurs sell their output to final good producers at the wholesale price  $P_t^W$ , so the gross markup of retail goods over wholesale goods is  $X_t = \frac{P_t}{P_t^W}$  and the marginal product of capital is  $\alpha \left( \frac{P_t^W}{P_t} \right) \frac{Y_t}{K_t}$ . Undepreciated capital is sold back to capital producers at the end of every period, so ex-post aggregate return to holding a unit of capital from  $t$  to  $t + 1$  is the sum of capital gains from reselling the capital and capital rents ( $Q_t$  is the real price of capital):

$$R_{t+1}^k = \frac{\alpha \left( \frac{P_t^W}{P_t} \right) \frac{Y_{t+1}}{K_{t+1}} + Q_{t+1}(1 - \delta)}{Q_t}. \quad (2.26)$$

Demand for household and entrepreneurial labour is obtained by setting the respective real wages  $w_t$  and  $w_t^e$  to marginal products of labour:

$$w_t = \Omega(1 - \alpha) \frac{Y_t}{H_t^p} \frac{P_t^W}{P_t}, \quad (2.27)$$

$$w_t^e = (1 - \Omega)(1 - \alpha) \frac{Y_t}{H_t^e} \frac{P_t^W}{P_t}. \quad (2.28)$$

### 2.3.4 The optimal debt contract

I modify the conventional structure of the optimal debt contract as suggested by Bernanke et al. (1999) to allow the bank lending rate be non-contingent on future shocks. In the original formulation of the financial accelerator framework the risk of entrepreneurial default is idiosyncratic and diversifiable, such that lending rate is contingent on future realisation of productivity shocks. In the model here credit risk is non-diversifiable and lending rate in debt contract is not made contingent on future productivity outcomes. Hence, in my formulation zero-profit condition of banks is replaced with incentive compatibility constraint that allows for non-zero profit outcomes for banks.

<sup>20</sup>It is assumed that entrepreneurs supply their labour inelastically (it does not enter their utility) with total entrepreneurial labour input being equal to one. The share of income that goes to entrepreneurial labour is set small enough in calibrations, as a result, there is no significant impact of this production function alteration on my results.



Entrepreneurs purchase capital, which is going to be used in production in  $t + 1$ , in the end of  $t$ . This capital acquisition is financed either through entrepreneurial net worth  $NW_t$  or by borrowing from banks  $L_t$ :

$$Q_t K_{t+1} = L_t + NW_t. \quad (2.29)$$

There is an idiosyncratic disturbance  $\omega^j$  to firm  $j$ 's return on capital, so that ex-post gross return to capital of firm  $j$  is  $\omega_{t+1}^j R_{t+1}^k$ .  $\omega^j$  is i.i.d. across entrepreneurs and time and  $F(\omega)$  is a continuous cumulative distribution function over a non-negative support  $\mathbb{E}(\omega^j) = 1$  with  $\mathbb{P}[\omega \leq x] = F(x)$ . Information about a realized return to capital of an entrepreneur is private and bank has to pay a monitoring cost to observe it. The monitoring cost<sup>21</sup> is a constant share  $\mu$  of the realized gross return on capital of a firm:  $\mu \omega^j R_{t+1}^k Q_t K_{t+1}^j$ .

$\bar{\omega}$  is as a cutoff value of idiosyncratic shock such that entrepreneurs, who receive any value lower than this threshold, are unable to repay their loans:

$$\bar{\omega}_{t+1} R_{t+1}^k Q_t K_{t+1} = r_t^L \pi_{t+1}^{-1} L_t. \quad (2.30)$$

Entrepreneurs with  $\omega^j \geq \bar{\omega}$  are able to pay back their loans and receive  $\omega^j R_{t+1}^k Q_t K_{t+1}^j - r_t^L \pi_{t+1}^{-1} L_t$ . Entrepreneurs with draws  $\omega^j < \bar{\omega}$  default and receive nothing, leaving the bank with  $(1 - \mu) \omega^j R_{t+1}^k Q_t K_{t+1}^j$ . Due to constant returns to scale assumption,  $\bar{\omega}$  specifies, how the expected aggregate gross return of entrepreneur  $R_{t+1}^k Q_t K_{t+1}$  is divided between the bank and the entrepreneur.  $\Gamma(\bar{\omega})$  is the expected gross share of entrepreneurial return going to the bank

$$\Gamma(\bar{\omega}) \equiv \int_0^{\bar{\omega}} \omega f(\omega) d\omega + \bar{\omega} \int_{\bar{\omega}}^{\infty} f(\omega) d\omega, \quad (2.31)$$

while  $\mu \Xi(\bar{\omega})$  is the expected monitoring costs:

$$\mu \Xi(\bar{\omega}) \equiv \mu \int_0^{\bar{\omega}} \omega f(\omega) d\omega, \quad (2.32)$$

where  $\Gamma'(\bar{\omega}) = 1 - F(\bar{\omega})$  and  $\mu \Xi'(\bar{\omega}) \equiv \mu \bar{\omega} f(\bar{\omega})$ . Hence, the net fraction of entrepreneurial return going to the bank is  $\Gamma(\bar{\omega}) - \mu \Xi(\bar{\omega})$ , and the share of return that stays with entrepreneur is  $1 - \Gamma(\bar{\omega})$ .

The optimal loan contract maximizes the gross return on capital of entrepreneur subject to incentive compatibility constraint of the bank:

$$\max_{K_{t+1}, \bar{\omega}_{t+1}} \mathbb{E}_t[(1 - \Gamma(\bar{\omega}_{t+1})) R_{t+1}^k Q_t K_{t+1}] \quad (2.33)$$

subject to

$$\mathbb{E}_t[(\Gamma(\bar{\omega}_{t+1}) - \mu \Xi(\bar{\omega}_{t+1})) R_{t+1}^k Q_t K_{t+1}] = r_t^e L_t / \mathbb{E}_t \pi_{t+1}, \quad (2.34)$$

where the incentive compatibility constraint formulates that the amount of real receipts of the bank loan branch from issuing loans at time  $t$  is equal to repayments to the bank parent

<sup>21</sup>The monitoring cost is also referred to in literature as auditing cost or the cost of bankruptcy.

branch under the rate of return that ensures the expected utility maximization according to (2.8) and where  $r_t^e$  is defined as:

$$r_t^e L_t = \mathbb{E}_t[(1 - F(\bar{\omega}_{t+1}))r_t^L L_t + (1 - \mu)V_{t+1}^d]. \quad (2.35)$$

Hence, the lending rate  $r_t^L$ , the amount of loans  $L_t$  issued and the interest rate  $r_t^e$  that the loan branch must pay back to the parent branch, satisfy the incentive compatibility constraint of the loan branch and maximize the entrepreneurs' expected return at the moment, when loans mature.

Solving this optimization problem yields the following optimality condition:

$$\frac{R_{t+1}^k}{r_{t+1}^e \pi_{t+1}^{-1}} = \frac{\Gamma'(\bar{\omega}_{t+1})}{(1 - \Gamma(\bar{\omega}_{t+1}))(\Gamma'(\bar{\omega}_{t+1}) - \mu \Xi'(\bar{\omega}_{t+1})) + \Gamma'(\bar{\omega}_{t+1})(\Gamma(\bar{\omega}_{t+1}) - \mu \Xi(\bar{\omega}_{t+1}))}, \quad (2.36)$$

which, together with the incentive compatibility constraint, pins down the optimal choice of capital  $K_{t+1}$  and of the threshold value of idiosyncratic shock to capital return  $\bar{\omega}_{t+1}$ . In its turn,  $\bar{\omega}_{t+1}$  and the variance of idiosyncratic productivity shock, being time-varying in the case of idiosyncratic uncertainty, specify the rate of default on loans, which triggers changes in risk premium that the banking sector charges. Additionally, these optimality conditions introduce the financial accelerator mechanism to the model: external finance premium increases in the leverage ratio of entrepreneurs.

### 2.3.5 Idiosyncratic uncertainty

To introduce idiosyncratic uncertainty, I assume that the variance of entrepreneurial idiosyncratic productivity shocks  $\omega$  is time-varying<sup>22</sup>.  $\omega$  is distributed log-normally - as noted earlier,  $\omega \sim \log N(1, \sigma_\omega^2)$ , hence, the log of  $\omega$  is normally distributed. I fix the mean of  $\omega$  to one, and define the variance of the log-normal distribution as  $(\sigma^{Id})^2 = \log(1 + \sigma_\omega^2)$ . This variance  $\sigma^{Id}$  is assumed to be varying and is affected by shock, which I refer to as the source of idiosyncratic uncertainty<sup>23</sup>. The log-deviation of  $\sigma_t^{Id}$  from its steady state is modeled as:

$$\log\left(\frac{\sigma_t^{Id}}{\sigma^{Id}}\right) = \rho_\sigma \log\left(\frac{\sigma_{t-1}^{Id}}{\sigma^{Id}}\right) + \sigma^\sigma \epsilon_t^\sigma. \quad (2.37)$$

$\sigma^\sigma$  is the standard deviation of innovations to  $\sigma_t^{Id}$  and  $\epsilon^\sigma$  follows standard normal distribution. Positive innovations to idiosyncratic uncertainty shocks increase the dispersion of entrepreneurial return to capital  $\sigma_t^{Id}$ . The illustration of this increase is given at Figure 2.2: higher variance of idiosyncratic shock to entrepreneurs' productivity changes the shape of the distribution shifting the mass of distribution to the left tail even when the mean of the distribution is unaffected. The intuition behind idiosyncratic shock is the following: the

<sup>22</sup>This formulation of idiosyncratic productivity draws from Christiano et al. (2010) and Dorofeenko et al. (2008).

<sup>23</sup>Empirical evidence that corroborates dispersion of idiosyncratic entrepreneurial productivity as a source of uncertainty has been provided, for example, in Bloom et. al (2012).

higher dispersion of productivity implies a higher probability of defaults on loans, and given costly state verification, a higher risk premium and lending rates, what leads to lower entrepreneurial demand for capital.

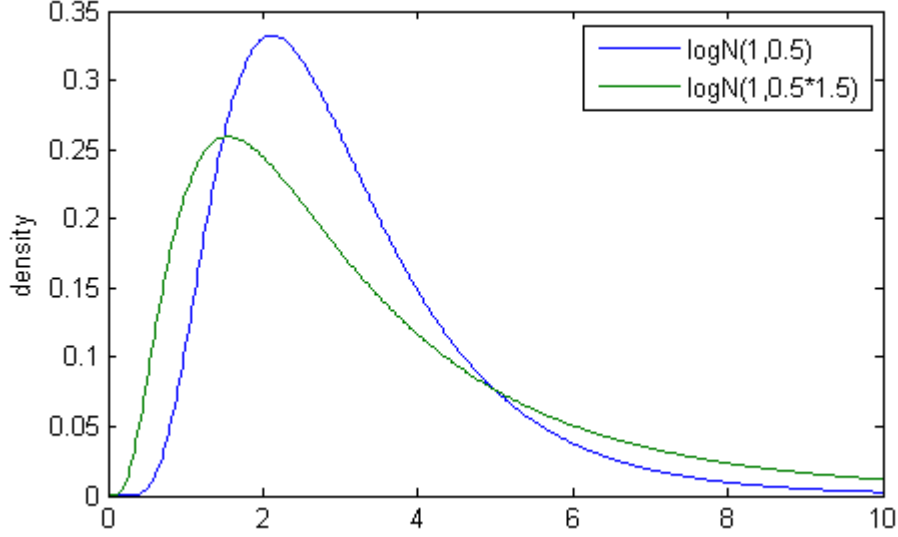


Figure 2.2: The effect of an idiosyncratic uncertainty shock.

### 2.3.6 Capital goods producers

A competitive sector of capital goods producers buys final goods from retailers as investment goods and existing undepreciated capital  $(1 - \delta)K_t$  from entrepreneurs and combines them to create capital for the next period  $K_{t+1}$ , which is then sold to entrepreneurs<sup>24</sup>:

$$K_{t+1} = I_t + (1 - \delta)K_t. \quad (2.38)$$

Capital adjustment costs are introduced to allow for the price of capital to vary, following Kiyotaki and Moore (1997). Drawing from Christensen and Dib (2008), I adopt a quadratic capital adjustment costs function, specified as  $\frac{\chi}{2}(\frac{I_t}{K_t} - \delta)^2 K_t$ . The optimization problem of the capital goods producers is to choose the value of investment  $I_t$  that maximizes their profits:

$$\max_{I_t} [Q_t I_t - I_t - \frac{\chi}{2}(\frac{I_t}{K_t} - \delta)^2 K_t]. \quad (2.39)$$

The first-order condition is

$$Q_t = 1 + \chi(\frac{I_t}{K_t} - \delta). \quad (2.40)$$

This standard condition of Tobin's Q relates the real price of capital to the marginal adjustment costs. Due to capital adjustment costs, the response of investment to various shocks

<sup>24</sup>I assume that capital producers rent the capital stock from entrepreneurs and use it to produce new capital; since this rent and subsequent return of capital happen within one period, the rental price is supposed to be zero.

slows down, which in its turn has an impact on the real price of capital. Variations in the price of capital, absent if there are not capital adjustment costs, contribute to volatility of net worth of entrepreneurs, what has a direct impact on workings of the financial accelerator mechanism. Hence, (2.40) represents the supply of capital and the demand for capital from entrepreneurs is formulated by (2.36) together with (2.34).

### 2.3.7 Retailers

The sector of retailers is introduced into the model to incorporate price rigidity. Specifically, I adopt Calvo price setting framework. There is a unit mass of monopolistically competitive retailers. They purchase wholesale goods from entrepreneurs at the nominal wholesale price  $P_t^w$  and resell them at their own retail price. Let  $Y_t(i)$  denote the quantity of output resold by retailer  $i$  and let  $P_t(i)$  denote the nominal price the retailer receives. Total final goods are a composite of individual retail goods

$$Y_t = [\int_0^1 Y_t(i)^{(\eta-1)/\eta} di]^{\frac{\eta}{\eta-1}}, \quad (2.41)$$

and the corresponding aggregate price index is given by

$$P_t = [\int_0^1 Y_t(i)^{1-\eta} di]^{\frac{1}{1-\eta}}, \quad (2.42)$$

where  $\eta > 1$  is elasticity of substitution in the retail market.

The standard monopolistic competition demand curve for individual retailers is

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\eta} Y_t. \quad (2.43)$$

The retailer chooses its sale price  $P_t(i)$  to maximize its profits taking as given the aggregate demand, price level and wholesale good price.

To incorporate price stickiness, I introduce Calvo pricing such that retailers are free to change their price each period with probability  $1 - \theta$ . Let  $P_t^*(i)$  denote the price chosen by retailers who are able to change their price. The aggregate price evolves according to (see technical appendix for details)

$$P_t = [\theta P_{t-1}^{1-\eta} + (1 - \theta)(P_t^*)^{1-\eta}]^{\frac{1}{1-\eta}}. \quad (2.44)$$

### 2.3.8 Monetary authority

I assume that monetary policy instrument is the nominal risk-free interest rate  $r_t^G$  that the central bank is able to set following the standard Taylor rule with interest rate smoothing, responding to deviations of inflation and output:

$$\log\left(\frac{r_t^G}{r^G}\right) = \rho_r \log\left(\frac{r_{t-1}^G}{r^G}\right) + \psi_\pi \log\left(\frac{\pi_t}{\pi}\right) + \psi_y \log\left(\frac{y_t}{y}\right) - \epsilon_t^m, \quad (2.45)$$

where  $\pi$  and  $y$  are the steady state levels of inflation and output and  $\epsilon_t^m$  in an i.i.d. white noise process denoting monetary policy shock. It is assumed that the supply of risk-free government bonds is perfectly elastic, such that any volume of demand for bonds from the banking sector is met.

### 2.3.9 Market clearing

The final good market clearing condition states that total output equals the sum of households' and entrepreneurial consumption, government spending, total resources used to create new capital goods and the monitoring costs of banks:

$$Y_t = C_t + C_t^e + G_t + I_t + \mu V_t^d. \quad (2.46)$$

### 2.3.10 Calibration

I calibrate the model at a quarterly frequency, setting fairly standard values for the DSGE model parameters. The discount rate  $\beta$  is set to 0.99 to target an annualized average risk-free interest rate of 3.8%, what is the average rate of three-month Treasury bills in 1983Q1-2016Q3. The capital share  $\alpha$  is set to 1/3, the share of entrepreneurial labour income  $(1 - \Omega)$  is set to 0.01, such that the labour share of households  $(1 - \alpha)(1 - \Omega)$  is 0.66. The parameter of leisure utility,  $\zeta$  (1.87) is set to target the time that households spend working to 1/3. The elasticity of substitution between final goods  $\eta$  is set to 5, and  $\theta$ , the Calvo parameter, is set to 0.75; these values imply that firms are able to adjust their prices on average once in four quarters and that a steady state value of markup of 25%.

I choose the quadratic adjustment costs functional form of the capital goods production function drawing from Christensen and Dib (2008), because quadratic adjustment costs, being a type of smooth "convex" adjustment costs that increase in the squared rate of investment, do not generate real options effects of uncertainty on economy. I want to analyze banks' precautionary mechanism of uncertainty as the main channel of influence of uncertainty on variables, that is why I aim at leaving aside other potential channels of impact. I set the marginal adjustment cost parameter  $\chi$  equal to 0.5882 - the parameter estimate from Christensen and Dib (2008). Depreciation rate  $\delta$  is set to its standard value of 0.025. The steady state share of government expenditures in total output is taken to be 0.2.

The values for monitoring costs  $\mu$ , for the steady state of the variance of idiosyncratic productivity shock  $\sigma^{Id}$  and for the survival rate of entrepreneurs  $\gamma$  are set jointly to match the data on entrepreneurial defaults (the average number of non-performing loans in 1988Q1-2016Q1 equal to 2.23%), the leverage ratio of entrepreneurs of 1.84 (measured as the average value of total assets to net worth of nonfinancial corporate business in 1983Q1-2016Q2)) and the real rate of return on capital expenditures of 15.4% in the steady state (estimate of Poterba (1998)). In that way, the fraction of realized payoffs lost in bankruptcy,  $\mu$ , is set to 0.21 (a number inbetween of that from Carlstrom and Fuerst (1997) - 0.25, and Bernanke et al. (1999) - 0.12), the survival rate of entrepreneurs  $\gamma$  is set to 0.95 (the value in Carlstrom

and Fuerst (1997) is 0.947, and the one in Bernanke et al. (1999) is 0.97), while steady state standard deviation of idiosyncratic productivity shock is set to 0.364 (somewhat higher than in Carlstrom and Fuerst (1997) - 0.207, and in Bernanke et al. (1999) - 0.28). The steady state annualized value of lending rate  $r^L$  is set to 6.86% to match the average of prime loan rate on historical data from 1983Q1 to 2016Q3. I draw the parameters of the Taylor rule followed by monetary authority from the estimated values in Christiano et al. (2010):  $\psi_\pi$  is set to 2.39,  $\psi_y$  - to 0.36 and  $\rho_r$  - to 0.85. From Christiano et al. (2010) I also use the estimated parameter values for autoregressive process of the government expenditure and variance of idiosyncratic productivity component of entrepreneurs<sup>25</sup>:  $\rho_g = 0.938$ ,  $\sigma^g = 0.021$ ,  $\rho_\sigma = 0.79$  and  $\sigma^\sigma = 0.05$ .

### 2.3.11 Solution method

The traditional linear approximation of the model solution implies that uncertainty shocks do not play a role due to certainty equivalence. For the variability of the second moment to enter the decision rules of economic agents, a third-order approximation is used. As discussed in Fernandez-Villaverde et al. (2010), the third-order Taylor expansion allows to simulate and to evaluate the effect of an uncertainty shock. I use the perturbation method to solve the model.

Dynare 4.4 is used to compute the third-order approximation around the non-stochastic steady state. As Fernandez-Villaverde et al. (2010) note, the third-order approximation moves the simulated paths of states and controls away from their steady state values, because the expected value of the variables depends on the variance of shocks<sup>26</sup>. Hence, I compute impulse responses as deviations from the mean of ergodic distributions of the data generated by the model, rather than deviations from the steady states, as this allows to take into account the second-order effects in a more comprehensive way. This approach is proposed by Fernandez-Villaverde et al. (2010) and is used in other studies investigating the effects of uncertainty shocks (see, for example, Born and Pfeifer (2011) and Cesa-Bianchi and Fernandez-Corugedo (2014)). The details of the computation of impulse responses functions are given in the Appendix.

I employ the pruning procedure proposed by Kim et al. (2008) to deal with the problem of explosive behaviour of the simulated time series when high-order perturbations are used to approximate the solution of the model.

## 2.4 The effect of uncertainty shocks

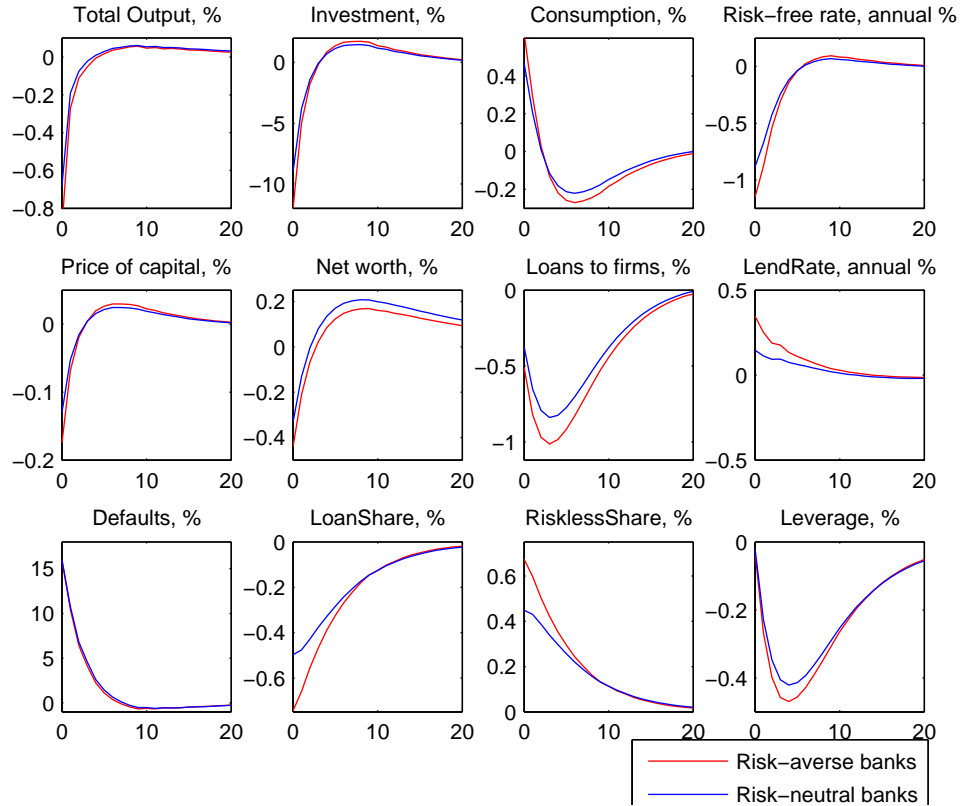
In this section I analyse the effect of an exogenous increase in idiosyncratic uncertainty on the model economy, and specifically, on banks' portfolio allocation. I consider two versions of the model - with risk-averse banking sector and with risk-neutral banks - to compare the

<sup>25</sup>Christiano et al. (2010) refer to idiosyncratic uncertainty shock as to 'risk shock'.

<sup>26</sup>As has been shown by Schmitt-Grohe and Uribe (2004), the expected value of any variable in high order approximations differs from its deterministic steady-state value.

features of portfolio reallocation following a positive uncertainty shock for two specifications of banking sector preferences. I find that, first, idiosyncratic uncertainty shock makes a significant impact of macroeconomic and credit variables; second, that banks' attitude to uncertainty makes a difference not only for portfolio allocation, but also for the dynamics of aggregate investment and output, and third, that financial accelerator mechanism works to amplify the effect of uncertainty shock. I analyse impulse responses to one standard deviation increase of idiosyncratic uncertainty innovation ( $\epsilon_t^g$ ). Figure 2.3 plots impulse responses of the model variables to an idiosyncratic uncertainty shock.

Figure 2.3: Impulse response functions to idiosyncratic uncertainty shock



When a positive idiosyncratic uncertainty shock hits, it means that the dispersion of idiosyncratic productivity of entrepreneurs increases. This implies that some entrepreneurs earn higher returns, while others bear greater losses. Hence, a greater fraction of entrepreneurs are further on the left tail of the productivity probability distribution function, such that more entrepreneurs are unable to repay their loans. As a result, the default rate on loans goes up. This can be seen on the figure 2.3, Defaults section. Defaults increase by 15% for both risk-neutral and risk-averse banks responding to a spike of idiosyncratic uncertainty. Due to costly state verification framework adopted in this model, higher defaults imply that banks' expected costs associated with bankruptcies go up, so banks of both types of specifications increase their lending rates to compensate for it. Lending rate of the risk-neutral banking sector goes up by 0.12 annual percent, while the one of the risk-averse bank increases it by

0.38 annual percent, and 0.26 pp of difference between them is explained by the working of precautionary mechanism. The higher cost of external debt induces entrepreneurs to reduce their demand for capital: firms borrow less and reduce their investment expenditures. Specifically, loans issuance goes down by 1% under risk-averse banks specification, and the issuance of loans of risk-neutral banks is 0.8%; 0.2% of the loans reduction is explained by the banks' precautionary motive. Notably, banks reallocate their portfolios following a positive idiosyncratic uncertainty shock: the share of risky loans goes down by 0.8% in case of risk-averse banking sector, and by 0.48% in case of risk-neutral banks with 0.32% of reduction of the risky loans share being explained by the precautionary motive of banks. The share of riskless bonds increases in portfolios of both types of banks: risk-neutral banks increase the share of risk-free bonds by 0.43%, and risk-averse banks increase it by 0.64%. Again, there's a role for the banks' precautionary motive, as there is a difference between the sizes of the increase. Crucially, the deleveraging of entrepreneurs is observed, and under the risk-averse type of banks preferences specification the reduction of the leverage is greater, than under the risk-neutral type.

There are two counteracting forces that have a potential to drive the entrepreneurial demand for capital. The partial equilibrium effect implies that the increased cost of borrowing induces entrepreneurs to reduce their optimal choice of leverage, such that capital demand also goes down. The general equilibrium effect takes into account that as a result of capital reduction, following a spike in uncertainty, the rental rate of capital goes up. Hence, entrepreneurs have an incentive to increase their leverage to benefit from this high value of capital return, which would give rise to an upward pressure on the demand for capital. The model simulations show that the partial equilibrium effect dominates the general equilibrium one: the forces that bring entrepreneurs' demand for capital down due to the increase of the interest rate on loans overpower the general equilibrium incentives to build up leverage because the return on capital has gone up. As a result, entrepreneurial leverage and investment fall.

The reduction of the demand for capital means that the price of capital goes down; the resulting net worth of entrepreneurs follows the dynamics of the price of capital closely: in both cases the negative impact of uncertainty with risk-averse banks exceeds the one with risk-neutral banks, meaning that the precautionary motive of banks is at work, however, its impact is rather small comparing to the impact on credit variables. Importantly, the rebound of the price of capital and of net worth occurs after 4 quarters from the impact of uncertainty shock. This rebound means that the demand for capital starts reviving after 3-4 quarters from the uncertainty shock impact. However, banks continue keeping their lending rates high - lending rates are still increased after 3-4 quarters from the shock impact, implying that the supply of credit stays depressed longer than the demand for credit following idiosyncratic uncertainty shock. Notably, the deleveraging process of the entrepreneurial sector continues to occur beyond 4 quarters after the uncertainty shock hits.

The reduction of investment after the positive idiosyncratic uncertainty shock is sizeable: it drops by 11% in the economy with risk-averse banks, and by 7.6% in the economy with



risk-neutral banks. 3.4% - a substantial difference - can be attributed to the precautionary motive of banks. Notably, the dynamics of investment following uncertainty shock - the drop and the following rebound in 4 quarters, - is in line with the result in Bloom (2009) for industrial production index. The decrease of aggregate output follows investment: it goes down by 0.8% under risk-averse banking sector and by 0.6% under risk-neutral one, with these results being roughly in line with the existing evidence on macroeconomic effects of uncertainty shocks.

The presence of financial accelerator mechanism amplifies the effect of uncertainty shock. In particular, due to reduced capital demand, the price of capital falls, making entrepreneurial net worth go down, what reduces the demand for capital further. Lower investment forces consumption to go up on the impact of uncertainty shock. A similar result is documented by Bloom et al. (2012) and by Christiano et al. (2014). In the latter, they draw an analogy of the effect of uncertainty shock to the increase of tax rate on capital return, which hinders saving and investment, while boosting consumption, in a way similar to a spike in the tax rate. However, the increase of consumption following uncertainty shock is clearly inconsistent with data. A possible way to fix the positive response of consumption to uncertainty shock in the model might be introducing the shock to the first moment - to the level of entrepreneurial productivity - simultaneously with the uncertainty shock. The reason to do that is that in practice the cases of elevated uncertainty often go along with the negative first moment shock, as suggested by Bloom (2014)<sup>27</sup>. Monetary authority responds to depressed output by easing monetary conditions: nominal interest rate is reduced, what together with heightened inflation implies decreasing real saving rate, such that households are encouraged to consume more and work less. After 2 quarters the negative wealth effect builds up, weaker capital demand acts to reduce output further, so the consumption also goes down. It features the additional 0.05% reduction after 6 quarters from the shock impact under the risk-averse bank specification comparing to the risk-neutral case.

It is important to notice, that this model is aimed to study the workings of the risk premia and risk aversion transmission mechanism of uncertainty with a particular focus on the precautionary motive of the banking sector. I reduced the amount of transmission mechanisms via which uncertainty might have an impact in the suggested model deliberately. One has to consider that this analysis is not supposed to be a comprehensive study of the effects of uncertainty shocks and should take it into account while making interpretations of the results obtained here.

To summarize, the suggested model produces significant negative effects of idiosyncratic uncertainty shock on macroeconomic variables - especially, on investment. Considering two versions of the model - with risk-neutral and risk-averse banks - allows to see that precautionary mechanism explains a substantial additional share of dynamics of credit variables: of the lending rate increase, of the decrease of the volume of loans issued, of the increase of the share of portfolio invested in risk-free bonds and of the leverage reduction. Financial accelerator plays a role and amplifies the impact of uncertainty shock.

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<sup>27</sup>I refer to Figure 5 of Bloom (2014) here.

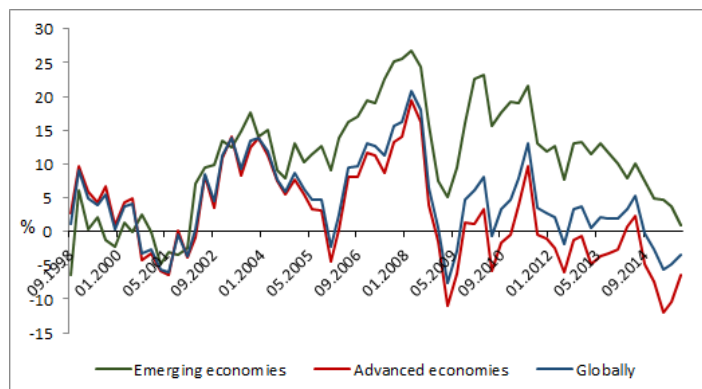
## 2.5 Conclusion

In this chapter I propose a DSGE model with a portfolio-optimizing banking sector to account for reallocation effects in banks' asset portfolios following uncertainty shocks found in the previous chapter. I model uncertainty as a time-varying cross-sectional dispersion of entrepreneurial productivity. This modelling conforms with the evidence of portfolio reallocation that I obtain as a response of banks to uncertainty shock, when microeconomic measures of uncertainty is used, in particular, cross-section standard deviation of firms profit growth and cross-firm stock return variation. I modify the standard financial accelerator framework of Bernanke, Gertler and Gilchrist (1999) to allow bank lending rates be non-contingent on aggregate shocks. Risk-averse banks face non-diversifiable credit risk and, by invoking a precautionary mechanism, increase risk premium following a spike in uncertainty by more than risk-neutral banks do. My result is in line with the conclusions of the modern portfolio theory, but the approach used here is advantageous comparing to that of the modern portfolio theory in several aspects. First, the risk of investment is not measured by variance of returns, but is a downside measure, what is a more adequate approach for the case of default risk. Second, the don't employ a quadratic utility function, but assume a more plausible representation of preferences characterized by constant relative risk aversion. Third, I adopt the general equilibrium approach, such that default risk is endogenous and also time-varying, as well as risk-free rate not being known in advance and being determined endogenously responding to movements in output gap and inflation. The suggested model allows to replicate the effects of uncertainty on the dynamics of banks' balance sheet items, observed in the data.

## 2.6 Appendix

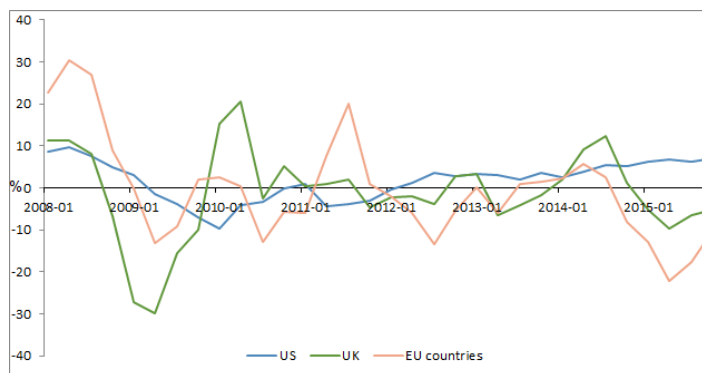
### 2.6.1 Credit market conditions

Figure 2.4: Bank credit growth



Note. The plotted numbers are year over year real quarterly credit growth figures. Source: BIS.

Figure 2.5: Bank credit growth, selected countries



Note. The plotted numbers are year over year real quarterly credit growth figures. Source: BIS.

## 2.6.2 Technical appendix

### Banking sector

At time  $t$  the balance sheet of the bank is:

$$D_t = L_t + B_t. \quad (2.47)$$

The profit of the bank is the difference between its income and expenses:

$$\mathbb{E}_t \Pi_{t+1} = (1 - F(\bar{\omega}_{t+1}))r_t^L L_t + (1 - \mu)V_{t+1}^d + r_t^G B_t - r_t^D D_t. \quad (2.48)$$

Using the simplifying assumption that  $r_t^G = r_t^D$  in each period  $t$ , I rearrange the expression for bank profit ( $\mathbb{E}_t \Pi_{t+1} = (1 - F(\bar{\omega}_{t+1}))r_t^L L_t + (1 - \mu)V_{t+1}^d + r_t^G B_t - r_t^D D_t$ ), between the third and the forth lines below I use the balance sheet identity holding at time  $t$ :

$$\begin{aligned} \Pi_{t+1} &= (1 - F(\bar{\omega}_{t+1}))r_t^L L_t + (1 - \mu)V_{t+1}^d + r_t^G B_t - r_t^D D_t = \\ &= (1 - F(\bar{\omega}_{t+1}))r_t^L L_t + r_t^G B_t - r_t^G D_t + (1 - \mu)V_{t+1}^d = \\ &= (1 - F(\bar{\omega}_{t+1}))r_t^L L_t + r_t^G (B_t - D_t) + (1 - \mu)V_{t+1}^d = \\ &= (1 - F(\bar{\omega}_{t+1}))r_t^L L_t - r_t^G L_t + (1 - \mu)V_{t+1}^d = \\ &= L_t((1 - F(\bar{\omega}_{t+1}))r_t^L - r_t^G) + (1 - \mu)V_{t+1}^d. \end{aligned}$$

The Lagrangian of the problem is given by

$$\mathcal{L}_t = \mathbb{E}_t \sum_{s=0}^{\infty} S_{t,t+s+1} u(\Pi_{t+s+1}). \quad (2.49)$$

The first order condition is:

$$\frac{\partial \mathcal{L}_t}{\partial \alpha_t} = \mathbb{E}_t [u'(\Pi_{t+1}) \frac{\partial \Pi_{t+1}}{\partial L_t} \frac{\partial L_t}{\partial \alpha_t}] = 0, \quad (2.50)$$

implying that

$$\mathbb{E}_t [\Pi_{t+1}^{-\kappa} (r_t^L (1 - F(\bar{\omega}_{t+1})) - r_t^G) D_t] = 0, \quad (2.51)$$

where I used the fact that  $\alpha_t = \frac{L_t}{D_t}$ . Because  $D_t$  is chosen, and therefore, known at time  $t$  and is a non-zero value, (2.51) means that the first order condition is actually

$$\mathbb{E}_t [\Pi_{t+1}^{-\kappa} (r_t^L (1 - F(\bar{\omega}_{t+1})) - r_t^G)] = 0, \quad (2.52)$$

or

$$r_t^L \mathbb{E}_t [\Pi_{t+1}^{-\kappa} (1 - F(\bar{\omega}_{t+1}))] = r_t^G \mathbb{E}_t [\Pi_{t+1}^{-\kappa}]. \quad (2.53)$$

By using the fact that  $r_t^L$  becomes known at  $t$  and applying the definition of covariance and the linearity property of expectations to (2.53), I expand this optimality condition to

$$r_t^{L,RA} [Cov(\Pi_{t+1}^{-\kappa}, (1 - F(\bar{\omega}_{t+1}))) + \mathbb{E}_t[\Pi_{t+1}^{-\kappa}] \mathbb{E}_t[(1 - F(\bar{\omega}_{t+1}))]] = r_t^G \mathbb{E}_t[\Pi_{t+1}^{-\kappa}] \quad (2.54)$$

hence,

$$r_t^{L,RA} \left[ \frac{Cov(\Pi_{t+1}^{-\kappa}, (1 - F(\bar{\omega}_{t+1})))}{\mathbb{E}_t[\Pi_{t+1}^{-\kappa}]} + \mathbb{E}_t[(1 - F(\bar{\omega}_{t+1}))] \right] = r_t^G. \quad (2.55)$$

To derive expression for the risk premium, I perform manipulations with (2.53):

$$\frac{r_t^L}{r_t^G} = \frac{\mathbb{E}_t[\Pi_{t+1}^{-\kappa}]}{\mathbb{E}_t[\Pi_{t+1}^{-\kappa} (1 - F(\bar{\omega}_{t+1}))]}, \quad (2.56)$$

then

$$\begin{aligned} \frac{r_t^L - r_t^G}{r_t^G} &= \frac{\mathbb{E}_t[\Pi_{t+1}^{-\kappa}] - \mathbb{E}_t[\Pi_{t+1}^{-\kappa} (1 - F(\bar{\omega}_{t+1}))]}{\mathbb{E}_t[\Pi_{t+1}^{-\kappa} (1 - F(\bar{\omega}_{t+1}))]} = \\ &= \frac{\mathbb{E}_t[\Pi_{t+1}^{-\kappa}] - Cov(\Pi_{t+1}^{-\kappa}, (1 - F(\bar{\omega}_{t+1}))) - \mathbb{E}_t[\Pi_{t+1}^{-\kappa}] \mathbb{E}_t[(1 - F(\bar{\omega}_{t+1}))]}{Cov(\Pi_{t+1}^{-\kappa}, (1 - F(\bar{\omega}_{t+1}))) + \mathbb{E}_t[\Pi_{t+1}^{-\kappa}] \mathbb{E}_t[(1 - F(\bar{\omega}_{t+1}))]} = \\ &= \frac{1 - \frac{Cov(\Pi_{t+1}^{-\kappa}, (1 - F(\bar{\omega}_{t+1})))}{\mathbb{E}_t[\Pi_{t+1}^{-\kappa}]} - \mathbb{E}_t[(1 - F(\bar{\omega}_{t+1}))]}{\frac{Cov(\Pi_{t+1}^{-\kappa}, (1 - F(\bar{\omega}_{t+1})))}{\mathbb{E}_t[\Pi_{t+1}^{-\kappa}]} + \mathbb{E}_t[(1 - F(\bar{\omega}_{t+1}))]} \end{aligned}$$

## Households

Households maximize their expected discounted lifetime utility

$$\max_{C_t, H_t, D_t} \mathbb{E}_t \sum_{k=0}^{\infty} \beta^k [\ln(C_{t+k}) + \zeta \ln(1 - H_{t+k}^h)] \quad (2.57)$$

subject to budget constraint

$$P_t C_t + D_t \leq W_t H_t^h + \Pi_t + r_{t-1}^D D_{t-1}. \quad (2.58)$$

The first-order conditions for consumption, labour and deposits are:

$$\beta^k C_{t+k}^{-1} P_{t+k}^{-1} = \lambda_{t+k} \quad (2.59)$$

$$\beta^k \zeta \frac{1}{1 - H_{t+k}^h} = \lambda_{t+k} W_{t+k} \quad (2.60)$$

$$\lambda_{t+k} = \mathbb{E}_{t+k} [\lambda_{t+k+1} r_{t+k}^D], \quad (2.61)$$

where  $\lambda_t$  is Lagrange multiplier. These first-order conditions could be written as

$$C_t^{-1} = \beta \mathbb{E}_t [C_{t+1}^{-1} r_t^D \pi_{t+1}^{-1}], \quad (2.62)$$

$$\zeta \frac{1}{1 - H_t^h} = C_t^{-1} W_t / P_t. \quad (2.63)$$

### Optimal debt contract

$\omega^j$  is assumed to be i.i.d. across entrepreneurs and time and follow log-normal distribution:  $\omega \sim \log N(1, \sigma_\omega^2)$ . Thus,  $\log(\bar{\omega}_{t+1}) \sim N(-0.5(\sigma_t^{Id})^2, (\sigma_t^{Id})^2)$ . Given this assumption, Bernanke et al. (1999) formulate the following distributions for the debt contract:

$$z_{t+1} = \frac{\ln(\bar{\omega}_{t+1}) + 0.5(\sigma_t^{Id})^2}{\sigma_t^{Id}} \quad (2.64)$$

$$\Xi(\bar{\omega}_{t+1}) = \Phi^N(z_{t+1} - \sigma_t^{Id}) \quad (2.65)$$

$$\Gamma(\bar{\omega}_{t+1}) = \Phi^N(z_{t+1} - \sigma_t^{Id}) + \bar{\omega}_{t+1}(1 - \Phi^N(z_{t+1})) \quad (2.66)$$

$$\Xi'(\bar{\omega}_{t+1}) = \frac{1}{\sigma_t^{Id} \sqrt{2\pi}} \exp\left(-\frac{(\ln(\bar{\omega}_{t+1}) + 0.5(\sigma_t^{Id})^2)^2}{2(\sigma_t^{Id})^2}\right) \quad (2.67)$$

$$\Gamma'(\bar{\omega}_{t+1}) = 1 - \Phi^N(z_{t+1}) \quad (2.68)$$

where  $\Phi^N(\cdot)$  is the standard normal c.d.f.

### Retailers

Retailers choose  $P_t^*(i)$  to maximize expected profits given by

$$\mathbb{E}_t\left[\sum_{k=0}^{\infty} \theta^k SDF_{t+k} \left(\frac{P_t^* - P_{t+k}^w}{P_{t+k}}\right) Y_{t+k}^*(i)\right], \quad (2.69)$$

where  $Y_{t+k}^*(i)$  is the demand in period  $t+k$  given price  $P_t^*$ . The first-order conditions from maximizing expected profits can be written as

$$P_t^* = \frac{\eta}{\eta - 1} \frac{\mathbb{E}_t \sum_{k=0}^{\infty} \theta^k SDF_{t+k} X_{t+k}^{-1} Y_{t+k} P_{t+k}^\eta}{\mathbb{E}_t \sum_{k=0}^{\infty} \theta^k SDF_{t+k} Y_{t+k} P_{t+k}^{\eta-1}}, \quad (2.70)$$

where  $X_t$  is the optimal price markup such that  $P_t = X_t P_t^w$ .

To implement Calvo pricing equations without log-linearization, I summarize the optimal pricing equation with two recursive equations linked by the optimal pricing equation (2.70). The numerator  $n_t$  and denominator  $d_t$  in equation (2.70) can be written recursively as

$$n_t = P_t^\eta Y_t X_t^{-1} + \theta \mathbb{E}_t[SDF_{t+1} n_{t+1}] \quad (2.71)$$

$$d_t = P_t^{\eta-1} Y_t + \theta \mathbb{E}_t[SDF_{t+1} d_{t+1}]. \quad (2.72)$$

Thus, the optimal pricing rule can be written as

$$P_t^* = \frac{\eta}{\eta - 1} \frac{n_t}{d_t}. \quad (2.73)$$

Let  $\hat{P}_t = P_t^* / P_t$  and  $F_{1,t} = P_t^{-\eta} n_t$ . From equation (2.71)  $F_{1,t}$  is written recursively as

$$F_{1,t} = Y_t X_t^{-1} + \theta \mathbb{E}_t[SD F_{t+1} \pi_{t+1}^\eta F_{1,t+1}]. \quad (2.74)$$

Substituting  $F_{1,t}$  into the rewritten optimal pricing rule (2.73) yields

$$P_t^* P_t^{-\eta} = \frac{\eta}{\eta - 1} \frac{P_t^{-\eta} n_t}{d_t}. \quad (2.75)$$

Let  $F_{2,t} = P_t^* P_t^{-\eta} d_t = \hat{P}_t P_t^{1-\eta} d_t$ . From equation (2.72)  $F_{2,t}$  is written recursively as

$$F_{2,t} = Y_t \hat{P}_t + \theta \mathbb{E}_t[SD F_{t+1} (\frac{\hat{P}_t}{\hat{P}_{t+1}}) \pi_{t+1}^{\eta-1} F_{2,t+1}]. \quad (2.76)$$

Using variables  $F_{1,t}$  and  $F_{2,t}$  the optimal pricing rule is

$$F_{2,t} = \frac{\eta}{\eta - 1} F_{1,t}. \quad (2.77)$$

$P_t^*$  is the same for all the retailers in each period. Therefore, in each period  $1 - \theta$  retailers reset their price to  $P_t^*$  and the aggregate price evolves according to

$$P_t = [\theta P_{t-1}^{1-\eta} + (1 - \theta)(P_t^*)^{1-\eta}]^{\frac{1}{1-\eta}}. \quad (2.78)$$

### 2.6.3 Impulse Response Functions Computation

In line with Fernandez-Villaverde et al. (2011) and the approach of Dynare to calculate impulse responses, the following procedure was used to compute impulse responses:

1. I draw a series of random shocks  $\epsilon_t = (\epsilon_t^A, \epsilon_t^W, \epsilon_t^\sigma, \epsilon_t^g, \epsilon_t^m)$  for 2096 periods. Starting from the steady state, I simulate the model using  $\epsilon_t$ .
2. I disregard the first 2000 periods as a burn-in. Based on the last 96 periods, I compute the mean of the ergodic distribution for each variable in the model.
3. Starting from the ergodic mean, I hit the model with a series of random shocks  $\epsilon_t^W$  for 96 periods. Simulation  $Y_t^1$  is obtained.
4. Obtain  $\tilde{\epsilon}_t^W$  by adding one standard deviation to  $\epsilon_t^W$  in period 1 and simulate the model starting from ergodic mean and hitting it with  $\tilde{\epsilon}_t^W$  to get  $Y_t^2$ .
5. I obtain IRFs as  $Y_t^2 - Y_t^1$ .



## Chapter 3

# Financial frictions and robust monetary policy in the models of New Keynesian framework

### 3.1 Introduction

Model uncertainty is not a trivial problem in monetary policymaking, as stated by policy-makers themselves, for example, in Greenspan (2004) and King et al. (2004). In particular, it is often, if not always, the case that central bank does not know the true structure of economy with full certainty, and thus has to allow for the possibility of economy to be represented by several models. The phenomenon of model uncertainty could be illustrated by a situation when the members of monetary policy committee do not agree on a model that represents the true structure of economy. Thus, a decision on the stance of monetary policy that has to be made by the committee has to be acceptable in all the alternative economy representations in order to be supported by all the committee members. In other words, the policy adopted should be robust to model uncertainty.

The particular relevance of model uncertainty is induced by the fact that in aftermath of the financial crisis of 2007-2009 there is a growing debate about what amplification mechanisms are conducive to economic distress. It has been widely acknowledged that financial factors have significantly contributed into the recent economic decline. But which of the factors play the principal role in economic developments, is the subject to disagreement; considerable uncertainty surrounds the "true" amplification mechanism. While there is a number of studies revealing empirical relevance of financial accelerator mechanism, for example, Carlstrom and Fuerst (1997), Bernanke et al. (1999), Mody and Taylor (2004), Peersman and Smets (2005), Almeida et al. (2006), Aliaga-Diaz and Olivero (2010), Cavalcanti (2010), there is also evidence on significance of collateral constraints as a factor behind aggregate fluctuations, for instance, in Fazzari et al. (1988), Gertler et al. (1991), Kashyap et al. (1994), Gilchrist and Himmelberg (1995), Hubbard et al. (1995). Financial accelerator as a principal factor behind the financial crisis of 2007-2009 has been advocated by Geanakoplos (2009) and

Krishnamurthy (2010), whereas collateral constraints are supported by Chatterjee (2010) and Peralta-Alva (2011 a, b). Other types of financial factors have also been suggested as potential drivers of the crisis: disruption of financial intermediation (Brunnermeier and Pedersen, 2009; Adrian and Shin, 2010; Gertler and Karadi, 2011), the transmission of contagion (Mendoza and Quadrini, 2010), asset price bubbles (Farhi and Tirole, 2011, Martin and Ventura, 2011), credit shocks (Christiano et al., 2008, Del Negro et al., 2010) and other. As a result, different models that incorporate financial factors have been developed recently.

Ultimately, there is no agreement about what financial factors are responsible for the recent economic decline, so there is no consensus about what is the "true" model that captures relevant type of financial frictions. Various models could be used as economy representations for analysis of monetary policy transmission mechanism with different degree of confidence about them describing real economy. Hereby arises the relevance of the issue of model uncertainty with respect to financial frictions.

Robustness of monetary policy to model uncertainty has been addressed by several methodological approaches. The first one, which was proposed in Brainard (1967) and developed further in Hansen and Sargent (2001a,b, 2002, 2003, 2007), considers robustness with respect to a benchmark model. Alternative models are supposed to lie around the benchmark at some small distance; thus, the set of alternative models could be thought of as being "local". Within this approach optimal policy is found by solving minimax problem for the "cloud" of models, which surround the benchmark. This methodology is employed in a number of works analyzing monetary policy robustness, for example, in Brock and Durlauf (2004, 2005), Giannoni (2002), Marcellino and Salmon (2002), Onatski and Stock (2002) and Tetlow et al. (2001). In these papers the focus is on the small set of reference models. The models with significantly different perspectives on inflation persistence, expectations formation and/or amplification mechanisms cannot be analyzed in the context of this methodological approach.

An alternative approach to address model uncertainty is model averaging. It was initially advocated by McCallum (1988) who claimed that robust policy should be defined as the one that works well enough in all the models considered; a robust rule might not be the best one for any of the models in the set, but it should be acceptable (in terms of losses or welfare costs) for all the alternative models. The principal value of this approach is that it does not require alternative models to be close enough to the benchmark. This is important for analysis of monetary policy transmission mechanism, because possible economy representations are not necessarily similar. Indeed, there are distinct models of economy that one would typically want to take into account, when looking for robust monetary policy; this is the case of uncertainty about the factors that are behind the financial crisis of 2007-2009. That is the reason why this chapter adheres to model averaging methodology.

Model averaging approach is adopted in a number of works with the aim of arriving at an interest rate rule - Taylor rule or another type of simple rule, - which is robust across a particular set of models. For example, Brock et al. (2007) examine uncertainty about the suite of backward-looking models in style of Rudebusch and Svensson (1999) and hybrid

models a la Rudebusch (2002), analyzing model uncertainty with respect to formulations of expectations and lag structure, while Levine et al. (2008) study different variants of Smets and Wouters model (2003). Levin and Williams (2003) search for a simple rule, which is robust to model uncertainty across the set of non-nested models: the basic New Keynesian model, the backward-looking model in style of Rudebusch and Svensson (1999) and a hybrid New Keynesian model with backward-looking elements (Fuhrer, 2000). Most of these works analyse the sets of models with competing perspectives about expectations formation and inflation persistence.

The focus of this chapter is different, the goal is to present the results complementary to those already existing in the literature. I aim to resolve the issue of model uncertainty about the financial factors that could be included to a DSGE model; hence I analyze the models that are different with respect to financial frictions incorporated in them. The models considered here are similar with respect to presence of nominal rigidities, the type of market structure, inflation persistence and expectations' formation. This setup allows to see, what impact do different financial factors have on welfare-optimizing policy rules. Second, it reveals whether the difference between amplification mechanisms in the models is big enough to generate non-robustness of optimal monetary policy rules. Relevance of robustness' study in this context is stipulated by the fact that adhering to a model that does not capture the "true" type of financial frictions might entail harmful welfare consequences. Thus, I characterize policy rules optimal for each of the models and evaluate welfare consequences of adopting suboptimal policy rules in all the alternative model economies. I also attempt to find policy rules that produce acceptable welfare outcomes in all the models considered: basic New Keynesian model (BNK) , financial accelerator model (FA) and a model with housing and collateral constraints (HCC); I assume that all the models have equal weights as possible economy representations.

I show that policy rule optimal for the BNK model is not robust to model uncertainty: welfare costs of adhering to it in alternative model economies featuring financial frictions are significant, being particularly high for the HCC model. This happens despite the fact that all the models considered adopt non-competing perspectives about expectations formation and inflation persistence. To see the contribution of financial factors to non-robustness of BNK-optimal rule I simulate the FA and the HCC models with financial frictions in them being inactive. When financial accelerator and collateral constraints mechanisms are "turned off", baseline New Keynesian optimal policy rule yields acceptable welfare outcomes in the FA and the HCC models. Hence, the presence of financial factors is the source of sensitivity of the FA and the HCC models and the reason of the baseline New Keynesian model's optimal rule non-robustness to model uncertainty.

I demonstrate that policy rules optimal for the FA and the HCC models are robust across the model set considered: adopting them in all the model economies produces acceptable levels of welfare costs. Despite the difference between the mechanisms of financial accelerator and collateral constraints - the former works through interaction between the firms' net worth, the external finance premium and the resulting demand for capital, while the latter

incorporates collateral constraints explicitly and ties the market price of housing to the ability to borrow by firms and households, - both the FA and the HCC models call for policy rate to respond to fluctuations in output. In other words, optimal policy in the models with financial factors requires direct output stabilization. This contrasts with optimal policy in the basic New Keynesian setup, when a policymaker aims at price stability and targets inflation, what is sufficient for attainment of the efficient allocation.

Finally, by employing the fault tolerance methodology, i.e. by considering welfare implications of deviations from the optimal policies, I obtain the set of policy formulations that are robust to model uncertainty. I demonstrate that the significant increase of output coefficient in the policy rule optimal for the basic New Keynesian model results in this rule being robust in the FA and the HCC models. I also ascertain that modest changes of parameter values in the FA and the HCC models' optimal rules do not entail negative welfare consequences in the alternative model economies. Additionally, increasing the coefficient of the interest rate smoothing in both the FA and the HCC models' optimal rules allows to improve welfare in the BNK model.

Monetary policy is modeled here in terms of optimal simple interest rate rules that are implementable, as, for instance, in Schmitt-Grohe and Uribe (2006), Faia and Monacelli (2005) and Mendicino and Pescatori (2005). I assume that a policymaker is able to commit to a rule. Rules' simplicity means that policy rate is a function of a small number of easily observable variables; implementability calls for unique rational expectations equilibrium delivered by a policy rule. Optimality criterion I use is utility-based welfare maximization (as in Schmitt-Grohe and Uribe, 2006 and Faia and Monacelli, 2005). This criterion differs from a conventional approach applied in literature on model uncertainty, which is a quadratic loss function minimization used, for example, in Cogley and Sargent (2005), Levin and Williams (2003) and Cogley et al. (2011). Using welfare maximization criterion to estimate parameters of optimized simple rules allows to stay consistent with microfoundations of the models. On the other hand, it is difficult to incorporate various preferences that a policymaker could have to increase policy efficiency<sup>1</sup>. Aiming at consistency with the models' microfoundations, this chapter uses maximization of welfare as a criterion of optimality.

In presenting the results this chapter follows an extension to the model averaging approach proposed by Brock et al. (2007). This extension consists in reporting the welfare consequences of adopting the optimized simple rules across alternative economy specifications, such that the effects of model uncertainty are substantialized. Following the terminology of Brock et al. (ibid.), I disclose the degrees of action dispersion - the parameter values of the policy rules optimized for each of the models across the set, and the degree of outcome dispersion - the evaluated welfare losses, associated with adopting the optimized policies in the alternative model economies.

Another extension of the model averaging approach adopted in this chapter is the fault tolerance methodology suggested by Levin and Williams (2003). The aim is to use the fault

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<sup>1</sup>For example, Caplin and Leahy (1996) and Goodhart (1996) refer to institutional reasons why policymaker might have a preference to avoid interest rate reversals. Lowe and Ellis (1997) advocate for importance of the financial market fragility issue; they argue that it is critical that a policymaker take it into account.

tolerance approach to ascertain, first, whether a robust policy could be obtained by an appropriate amendment of non-robust monetary policy rules, and second, whether under the robust policy rule welfare could be improved across the models by deviating from the optimized policy. I propose an extension to this approach and evaluate how sensitive are model economies in the welfare sense to deviations from the optimized policy rules, what enables me to establish whether and how a policymaker could promote welfare in the alternative economy representations by amending a particular policy rule she chooses to follow. I find that a modified policy rule optimal for the BNK model is robust when the output coefficient is sufficiently increased. Though, this modified policy rule is not an optimal one for any of the models considered, i.e. it does not deliver the highest level of welfare in any of the them, - it yields acceptable welfare outcomes in all the alternative economy representations.

## 3.2 Alternative model economies

To analyse the impact of different amplification mechanisms on monetary policy robustness, the models considered here are similar in many respects but financial frictions. The suite of models includes the basic New Keynesian model, the financial accelerator model and the model with housing and collateral constraints (HCC). All the models are forward-looking, do not incorporate inflation persistence and account for nominal stickiness and monopolistic competition. In all the models monetary policy plays an active role in stabilizing economy because of short-term nominal inertia. All the models are allowed to be hit by monetary policy and TFP shocks. In what follows I briefly introduce the main characteristics of the models<sup>2</sup>. Equilibrium conditions and parameters' calibration used for simulations are given in the Appendix.

### 3.2.1 Basic New Keynesian model

The basic New Keynesian model is a common reference in the monetary policy analysis. It is often used as a benchmark in macroeconomic literature, because it combines in itself parsimony, theoretical foundations, empirical relevance and practical usefulness. In its original version as suggested by Clarida et al. (1999) BNK does not incorporate any financial factors and accounts for purely forward-looking output and inflation; its dynamics is entirely due to exogenous processes without endogenous persistence and outcomes depending on agents' expectations. The baseline BNK model features no capital and investment.

The version of the BNK model considered here is taken in its standard form as in Walsh (2010). Government spending is added to the model to introduce the demand side shocks, which are absent in the model formulation of Walsh. Thus, three types of exogenous disturbances are accounted by the BNK model here: monetary policy, TFP and government spending shock.

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<sup>2</sup>Detailed exposition of the models considered is given in Walsh (2010), Christensen and Dib (2008) and Iacoviello (2005).

BNK model features a negative effect of interest rate on output. Current output depends on expectations of future consumption expenditure. Nominal prices are set based on future marginal costs; this indicates no inertia in inflation. Ultimately, inflation depends on movements in marginal costs, associated with variation in excess demand. The monetary policy rule that closes the model is presented in the next section. Gali (2008) and Walsh (2010) demonstrate that the efficiency is fully restored in the BNK model, when monetary policy aims to stabilize the economy's average markup at its frictionless level.

### **3.2.2 Financial accelerator model**

This model incorporates the financial accelerator mechanism developed in Bernanke and Gertler (1989). The borrowers and lenders are modelled explicitly and are incorporated into an otherwise standard New Keynesian setup with nominal stickiness and monopolistic competition. Frictions arise due to the agency problem caused by informational asymmetries. Specifically, the profitability of entrepreneurs, who borrow funds from risk-neutral banking sector, is a private information. The costly state verification setup suggested by Townsend (1979) is adopted, such that asymmetric information gives rise to agency costs, which are often referred to as monitoring costs, that the lenders need to pay to observe the ex-post entrepreneurial productivity. In particular, when an entrepreneur cannot repay the debt, the lender pays verification cost as a share of entrepreneur's assets and takes over her entire project. Bernanke et al. (1999) derive the optimal debt contract structure and show that the entrepreneurial debt payment is independent of realization of her idiosyncratic productivity. The model manifests the cost of external funds higher than the cost of internal funds, with the former related to borrowers' net worth inversely. The dynamics of net worth follows the movements of the price of capital. Hence, the changes in the demand for capital affecting the price of capital trigger the movements of entrepreneurial net worth. As a result, the level of the external finance premium also changes, and this change reinforces the initial movements of the demand for capital, such that the demand side shocks are amplified.

Importantly, the role of the financial accelerator mechanism in driving the changes of demand for capital, and hence, investment, depends on the nature of the shock generating them. As demonstrated by Christensen and Dib (2008), the financial accelerator propagates and amplifies the effects of demand shocks, - like monetary policy, money demand and preference shocks, - on investment. At the same time, the financial accelerator pushes down the response of investment to supply side shocks - for example, to technology and investment-specific shocks. As emphasized by Bernanke et al. (1999) and Christensen and Dib (2008), investment specific shock allows to explain important features of business cycle data, and hence is an important exogenous force driving the model.

Real distortions in the model imply that there is a trade-off for a policymaker between inflation and output stabilization.

### 3.2.3 Model with housing and collateral constraints

One of the sources of frictions in this model is the difference in discount rates of different agents: entrepreneurs, impatient (or liquidity-constrained) and patient (or unconstrained) households. As suggested in Iacoviello (2005), HCC model incorporates housing used by borrowers - entrepreneurs and constrained households - as collateral. Hence, this model accounts for an additional (as compared to the FA model) type of asset - housing, with house prices affecting the borrowing capacity of the debtors. This relationship constitutes a channel, via which the model's endogenous propagation mechanism works beyond the conventional Bernanke et al. (1999) financial accelerator channel. Constrained households are assumed to have a strong preference for current consumption, such that growing housing prices induce more than proportional rise of borrowing and consumption, which in its turn has an impact on aggregate output. Thus, the demand shocks are amplified in the HCC model. At the same time, inflation depresses the impact of supply shocks that induce negative correlation between output and inflation. So, the impact of supply shocks in this model is contracted in the same way as in the FA model. In addition to monetary policy and productivity shocks the HCC model accounts for cost-push shock, housing price shock and preference for housing shock.

## 3.3 Monetary Policy and Welfare Measure

### 3.3.1 Optimized policy rules

I assume that monetary policy is conducted by means of interest rate rule - a plan for the path of interest rate that a policymaker commits to abide forever. This rule provides a clear policy objective, but in practice there is room for discretion. Interest rate reaction function is simple, optimal and implementable as suggested by Schmitt-Grohe and Uribe (2006). In this formulation, interest rate should be a function of a small number of easily observable variables. Second, this reaction function should maximize social welfare. Third, the rule should deliver a unique rational expectations equilibrium. The type of policy rule I adopt is a standard one, incorporating interest rate smoothing and a response to deviations of inflation and output from their steady state values. In particular,

$$\ln(r_t/r) = \rho * \ln(r_{t-1}/r) + \alpha_\pi * \ln(\pi_t/\pi) + \alpha_y * \ln(y_t/y) + \epsilon_t \quad (3.1)$$

where  $r_t$  is the gross nominal interest rate,  $\pi_t$  is inflation rate,  $y_t$  is output and variables without subscripts denote steady state values of respective variables. I assume that a policymaker commits to the rule (3.1) and evaluates the parameters  $\rho$ ,  $\alpha_\pi$  and  $\alpha_y$  by maximizing social welfare subject to the models' equilibrium conditions.

The welfare associated with the optimized policy rule conditional on a particular state of economy in period 0 is:

$$\widetilde{W}_0 = E_0 \sum_{t=0}^{\infty} \beta^t U(\widetilde{C}_t, \widetilde{N}_t) \quad (3.2)$$

where  $E_0$  is conditional expectation over the initial state and  $\widetilde{C}_t$  and  $\widetilde{N}_t$  are contingent plans for consumption and hours worked under the optimized policy rule. Analogously, the welfare associated with the alternative policy rule conditional on a particular initial state of economy is an appropriate aggregation of contingent plans for consumption and hours under an alternative rule  $C_t^a$  and  $N_t^a$ :

$$W_0^a = E_0 \sum_{t=0}^{\infty} \beta^t U(C_t^a, N_t^a) \quad (3.3)$$

The use of conditional expectation of the discounted utility of representative agent allows to account for transitional effects from steady state to a path implied by alternative policy rules.

For each model I search numerically for the values of parameters  $\rho$ ,  $\alpha_\pi$  and  $\alpha_y$  that maximize households' welfare. These parameter values specify optimized simple rules for each model. Parameter  $\rho$  is restricted to lie on the interval  $[0, 0.99]$ ,  $\alpha_\pi$  - on the interval  $[1, 3]$  (values below 1 result in rational expectations equilibrium indeterminacy) and  $\alpha_y$  - on the interval  $[0, 3]^3$ . To implement this numerical search I solve the models by second-order approximation of the policy functions around non-stochastic steady state. The parameters of the optimized policy rules that maximize representative agent utility-based welfare are shown in the Table 3.1.

Table 3.1: Models' optimal rules - utility-based welfare maximization

Model	$\rho$	$\alpha_\pi$	$\alpha_y$
BNK	0.52	3	0
FA	0.16	3	0.78
HCC	0	3	0.86

Policy rule optimal for the BNK model features strong reaction to variations in inflation ( $\alpha_\pi = 3$ ), no response to output gap ( $\alpha_y = 0$ ) and a moderate degree of interest rate smoothing ( $\rho = 0.52$ ), what is a well-known result for this type of model; see, for example, the result of optimal simple rules evaluation in Levin and Williams (2003), Schmitt-Grohe and Uribe (2006) and Justiniano et al. (2013). The FA optimized rule is characterized by a sizable reaction to deviations of output ( $\alpha_y = 0.78$ ), strong responses to inflation ( $\alpha_\pi = 3$ ) and a relatively small degree of policy rate inertia ( $\rho = 0.165$ ). Rule optimal for the HCC model features the strongest among all the models reaction to output fluctuations ( $\alpha_y = 0.86$ ), strong reaction to inflation ( $\alpha_\pi = 3$ ) and no interest rate smoothing ( $\rho = 0$ ).

All the models' optimized rules feature importance of inflation stabilization:  $\alpha_\pi$  coefficient takes its highest value 3 across all the models. This happens due to nominal rigidities present in all the models and due to inflation being forward-looking. Price dispersion is the

<sup>3</sup>These intervals are conventional for the search of optimal parameter values in the literature, see, for example, Schmitt-Grohe and Uribe (2006). Values outside of these intervals are disregarded on the grounds that they don't result in non-negligible welfare improvement.



main source of welfare costs in all the models, hence the call to minimize it. The optimized rules differ in their values of  $\rho$  and  $\alpha_y$ . In the FA and the HCC optimized rules larger response of policy rate to deviations in output and small/no degree of interest rate smoothing characterize their aggressiveness. First, the presence of real distortions in the FA and the HCC models implies that a policymaker faces the trade-off in output and inflation stabilization, i.e. that the "divine coincidence" does not hold with respect to these models. The FA and the HCC optimized rules call for sizable responses to output fluctuations, what makes them more aggressive comparing to the BNK rule. In the BNK model optimized policy replicates the flexible price equilibrium allocation (Gali, 2008); strict inflation targeting is optimal in this model as policymaker does not face a meaningful policy trade-off. Second, the absence or a very small interest rate inertia in the FA and the HCC optimized rules features their aggressiveness, as it implies that policy rate should only react to variables' fluctuations in the current period with no backward-looking reaction component. This contrasts with the sizable degree of inertia of the BNK policy rule that calls for more gradual changes in policy in the short run<sup>4</sup>. Smooth changes in policy rate are welfare-improving in the BNK model, because they facilitate monetary policy anticipation for the agents and thus improve short run trade-off between output and inflation stabilization in absence of real distortions.

The origins of the differences in three optimized policy rules could be illustrated by the differences in targets of policymakers identified in the attempts to approximate social welfare in three models with quadratic loss function of a policymaker. While the utility-based welfare measure of the BNK model is approximated by the weighted average of inflation and output variability<sup>5</sup>, this is not the case for the financial frictions models. Though, the exact approximation of the social welfare in the FA model by the quadratic loss function of a policymaker does not exist, it has been shown by Edge (2003) that lifetime utility-based welfare of the model with endogenous capital (without the financial accelerator mechanism) could be approximated by variances of inflation, output gap and investment spending gap. It is reasonable to guess that approximation of the welfare measure for the FA model by the quadratic loss function (if it exists) also includes investment spending gap, so that composition of output matters in this model<sup>6</sup>. Andres et al. (2010) argues that welfare losses in the HCC model could be approximated by variability of consumption gap between constrained and unconstrained households and the distribution of housing between firms, constrained and unconstrained households in addition to variability of inflation and output. Hence, there are differences in criteria, which are used to obtain optimized rules for the models considered: in addition to minimizing variability of inflation and output within the BNK model, in the FA it is optimal (presumably) to minimize the variability of the investment spending gap, while in the HCC model - to minimize the consumption gap between constrained and unconstrained households, while also taking into account the distribution of housing between firms, and both types of households. Hence, the evaluated parameter values in the

<sup>4</sup>Significant degree of interest rate smoothing as an optimal monetary policy response has also been found in Schmitt-Grohe and Uribe (2006).

<sup>5</sup>See Woodford (2003), Gali (2008) and Walsh (2010).

<sup>6</sup>See Edge (2003) for details.

optimized rules in the Table 3.1 reflect the differences in the optimization criteria.

To see the difference in the results obtained by using different approaches, I also use an alternative way to find the optimized policy rules. In particular, I use quadratic loss function minimization to get the values of parameters  $\rho, \alpha_\pi, \alpha_y$  in (3.1). This optimization criterion is commonly used in the literature on monetary policy robustness<sup>7</sup>. Period objective function of policymaker takes the form:

$$L = var(\pi_t) + \lambda_y * var(y_t) + \lambda_{\Delta r_t} * var(\Delta r_t) \quad (3.4)$$

Social welfare in the BNK model is shown to be approximated by this type of quadratic loss function<sup>8</sup>, what is not the case for the FA and the HCC models. To the best of my knowledge, welfare in these models is not approximated by a quadratic type of loss function, due to computational challenges arising from the relatively bigger size of these models and from the presence of financial distortions in them. The use of quadratic loss function for the FA and the HCC models to evaluate welfare costs could be justified by the fact that policymaker might have preferences for inflation targeting, interest rate smoothing and output gap stabilization. In fact, the ability of the loss function (3.4) to capture different types of policymaker's preferences makes this criterion more flexible than representative agent welfare maximization optimization criterion, because it can be adjusted to account for various type of policymaker's preferences. For example, setting  $\lambda_y$  and  $\lambda_{\Delta r_t}$  to zero allows to consider the case of strict inflation targeting policy. Setting  $\lambda_y = 1$  enables to analyse the case of equal preferences for inflation and output gap stabilization, whereas  $\lambda_y$  exceeding  $\lambda_\pi$  is the case of a stronger preference for output gap stabilization. Additionally, forgoing the idea that social welfare is represented by the lifetime utility of a representative agent, could be regarded as a flexible and beneficial characteristic of this approach, because it allows to take into account inequality issues/welfare distribution considerations in the analysis. In any case, as summarized by Levin and Williams (2003), there is no consensus about the "correct" values of weighting parameters  $\lambda_y$  and  $\lambda_{\Delta r_t}$ . I use the loss function specification for the grid of values for  $\lambda_y$  and  $\lambda_{\Delta r_t}$ :  $\lambda_y = 0, 0.5, 1$  and  $2$  and  $\lambda_{\Delta r_t} = 0, 0.5$  and  $1$ . In this chapter I report the results for two sets of preferences: strict inflation targeting, when  $\lambda_\pi = 1, \lambda_y = 0$  and  $\lambda_{\Delta r_t} = 0$ , and inflation and output gap stabilization, when  $\lambda_\pi = 1, \lambda_y = 1$  and  $\lambda_{\Delta r_t} = 0$ .

Table 3.2: Optimized rules under quadratic loss function minimization: strict inflation targeting.

Model	$\rho$	$\alpha_\pi$	$\alpha_y$
BNK	0.85	3	0
FA	0.5	3	0
HCC	0.85	3	0
RS	0.7	2.15	1.5

The parameters of the optimized policy rules calculated to minimize the quadratic loss

<sup>7</sup>See, for example, Clarida et al. (1999), Cogley and Sargent (2005), Levin and Williams (2003), Cogley et al. (2011), etc.

<sup>8</sup>See Woodford (2003), Gali (2008) and Walsh (2010) for details of the derivation.

function are shown in the Table 3.2 for the case of strict inflation targeting, and in the Table 3.3 for a policymaker's preference for inflation and output gap stabilization. Using quadratic loss function minimization as an optimization criterion, I include Rudebusch and Svensson (1999) (RS) macroeconometric model in the set of models. This is done to see the effect of expectations about inflation formation on the parameters' values of the optimized rule, because the RS model incorporates a significant degree of inflation persistence, being otherwise similar to the BNK model<sup>9</sup>.

The results of using the loss function minimization to find the optimized policy rules show that in case of strict inflation targeting all the NK models feature zero responsiveness to changes in output:  $\alpha_y = 0$ , strong response to changes in inflation:  $\alpha_\pi = 3$  and a significant degree of interest rate smoothing:  $\rho = 0.5$  for the FA model and  $\rho = 0.85$  for the BNK and the HCC models. Comparing to the use of the utility-based welfare measure as an optimization criterion, there is a substantial difference: it is not optimal to respond to changes in output, when the goal is to minimize the quadratic loss function of a policymaker. This demonstrates that choosing a criterion for policy optimization is not a trivial matter. It also provides an additional support for the considerations discussed above, in particular, that a 'true' quadratic loss function optimization criterion for the models with financial frictions should incorporate additional components: presumably, investment spending gap for the FA model and variability of consumption gap between constrained and unconstrained households and the distribution of housing between agents. Importance of responding to changes in output, when utility-based welfare optimization criterion is used, is driven by taking into account these additional components.

Another interesting result is, that when the model features by some degree of backward-looking choices, it is optimal to respond to changes in output even in the case of the strict inflation targeting. This is due to the fact that the optimal level of  $\alpha_y$  coefficient for the RS model has non zero value in contrast to all the other models:  $\alpha_y = 1.5$ , while the responses to changes in inflation are less strong:  $\alpha_\pi = 2.15$ .

Table 3.3: Optimized rules under quadratic loss function minimization: inflation and output gap stabilization.

Model	$\rho$	$\alpha_\pi$	$\alpha_y$
BNK	0.7	2.2	0.4
FA	0.35	2.9	2.6
HCC	0.9	1.4	2.7
RS	0.1	2.4	2.6

The results in the Table 3.3 show that when a policymaker puts equal weights on stabilizing output and inflation, all the models feature significant responses to deviations in output, with the responses being the smallest for the BNK model  $\alpha_y = 0.4$  and the largest for the HCC model  $\alpha_y = 2.7$ . The responses to changes in inflation are smaller comparing to strict inflation targeting case. This stands in the marked contrast with the results of utility-

<sup>9</sup>This model is not based on microfoundations, so it is impossible to analyse it in line with the BNK, the FA and the HCC models, when utility-based welfare measure is used to optimize policy rules.

based welfare maximization presented in the Table ?? and thereby emphasizes the critical differences in policy rules optimized with respect to different criteria.

### 3.3.2 Welfare costs and robustness

Welfare costs  $\lambda$  are measured as a percentage of consumption that a representative household would agree to be compensated with in order to gain the same level of lifetime utility as under the optimized rule:

$$W_{0,\lambda} = E_0 \sum_{t=0}^{\infty} \beta^t U(C_t^a(1 + \lambda), N_t^a) = \widetilde{W}_0 \quad (3.5)$$

I evaluate welfare costs in each model by numerical search for  $\lambda$  over the grid so that condition (3.5) is satisfied. I resort to numerical solution due to technical complexity of derivation of  $\lambda$  as a solution to (3.5) in the analytical form. In calculating welfare costs for the HCC model I only account for welfare of patient (unconstrained) households; welfare of entrepreneurs and constrained households is disregarded as the fractions of their consumption in the total consumption expenditure are negligibly small.

To draw inference about the rules' robustness, I simulate three model economies adopting all the optimized policy rules and evaluate welfare costs of adopting each of them. In particular, I first evaluate welfare in the BNK, the FA and the HCC models applying alternative specifications of (3.1), when the latter are optimized for either model economy. Second, I compute welfare costs of adopting the BNK, the FA and the HCC optimized policy rules relative to the first-best policy rule in each model economy. In doing this I rely on the second-order approximation of the model's solution to account for the nonlinear dynamics of the models<sup>10</sup>.

Table 3.4: Conditional welfare costs

Model	BNK rule	FA rule	HCC rule
BNK	0	0.002	0.003
FA	1.16	0	0.001
HCC	7.67	0.06	0
FA no frictions	0.55	n/a	n/a
HCC no frictions	1.66	n/a	n/a
FA no frictions and model-specific shocks	0.21	n/a	n/a
HCC no frictions and model-specific shocks	0.64	n/a	n/a

Conditional welfare costs are measured by  $\lambda * 100\%$ .

The results of the welfare costs estimation according to (3.5) are shown in the Table 3.4. The BNK rule adopted in the FA model entails welfare costs of 1.16% of consumption of a representative agent, in the HCC model - 7.67% of her consumption. Using the informal threshold of unacceptable losses at the level of 0.8 – 1% of consumption as suggested in Schmitt-Grohe and Uribe (2006), I conclude that adopting the BNK optimized in the FA and

<sup>10</sup>Kim and Kim (2000) show, that the use of the first-order approximation yields inaccurate results for welfare evaluation.

the HCC models causes substantial welfare losses. On the other hand, adopting both the FA and the HCC rules delivers acceptable welfare losses in the BNK, the FA and the HCC models. Assuming that suboptimal rule is adopted, i.e. a policymaker didn't choose the model that represents the 'true' structure of economy to derive the optimized rule, the smallest value of welfare losses are obtained when the HCC optimized rule is adopted in the alternative model economies: the welfare losses in the BNK model are 0.003% of a representative agent consumption, while the losses in the FA mode are 0.001% of consumption. Hence, the HCC optimized rule, featuring no interest rate smoothing and a significant output stabilization, could be regarded as the first-best policy to adopt in case of model uncertainty about financial factors. At the same time the HCC model is the most sensitive to suboptimal policy formulations, due to the fact that welfare losses in the HCC model are the high, when the BNK rule is adopted - 7.67%, and 0.06% under the FA optimized rule<sup>11</sup>.

The BNK optimized rule yields welfare detrimental outcomes in the models with financial frictions: 1.16% in the FA model and 7.67% in the HCC model, making this rule non-robust across the set of the models considered. To check whether this non-robustness is due to financial frictions, the BNK rule is adopted in the FA and HCC model economies with financial frictions being inactive. I disactivate the financial accelerator mechanism in the FA model by setting the zero responsiveness of the external finance premium to the level of net worth position of borrowers, such that the borrowing costs are not related to the indebtedness of entrepreneurs. The resulting demand for capital does not depend of the leverage position of borrowers. The FA model with the inactive financial accelerator mechanism is a NK model with capital and capital adjustment costs. Hence, the presence of capital and capital adjustment costs is what makes is different from the BNK model. In the HCC model I disactivate the collateral constraints mechanism by closing the asset price channel, such that the price of housing does not affect firms' and households' ability to borrow. Specifically, I modify the housing/consumption margin conditions to make this amendment. Additionally, I set that the debt in the HCC model is indexed, not nominal, as in its original version. This is done to eliminate the debt deflation effect in this model.

Table 3.4 shows the results of the BNK rule being adopted by the FA and the HCC models, when financial frictions are disactivated in them. There is a substantial improvement of the BNK rule performance across the other models, when the frictions are not active. The FA model without financial accelerator mechanism features 0.55% of welfare losses, while the HCC model without the housing and collateral constraints mechanism delivers 1.66%, of welfare losses, what is substantially smaller than the losses in the full-version FA and HCC models. Therefore, it can be concluded that these are the financial frictions that are responsible for the BNK optimized rule non-robustness across the model set. As the next step, I disactivate exogenous model-specific shocks that drive the model's fluctuations to see their contribution in the losses generated by following the BNK rule. The welfare improves further: the losses in the FA model with no frictions and investment-specific and preference

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<sup>11</sup>A similar result of the most sensitive model yielding the robust policy rule has been obtained by Cogley et al. (2011).

shocks are 0.21%, while in the HCC model with no frictions and no housing and cost-push shocks - 0.64%. Hence, a part of the high level of welfare costs generated by the full-version FA and HCC models can be attributed to the workings of model-specific shocks. Disactivating the frictions and model-specific shocks in the FA and HCC models removes, at least partly, the trade-off between inflation and output stabilization; this result is consistent with the findings obtained by Justiniano et al. (2012). I conclude that this is due to model-specific financial frictions and shocks in the FA and the HCC models, why the BNK optimized rule featuring no responsiveness to changes in output is non-robust across the set of otherwise similar NK models, with the impact of financial frictions being larger.

Importantly, the BNK model is not sensitive to suboptimal changes of the policy rule adopted. In particular, when a policymaker responds to changes in output, following the FA or the HCC optimized rules, the BNK model yields low level of welfare costs: 0.002% of consumption of the representative agent under the FA optimized rule and 0.003% under the HCC optimized rule. Thus, I conclude that comparing to the FA and the HCC models, the BNK model is tolerant to suboptimal changes in monetary policy rule. I also show the validity of this result in the next section by the means of fault tolerance analysis.

Interestingly, the FA and the HCC models are mutually tolerant to adopting suboptimal policy rules: welfare costs of following the HCC optimized rule in the FA model is 0.001%, while the costs of adopting the FA optimized rule in the HCC model are 0.06%. This result is due to similarity of the FA and HCC optimized policies featuring responses to changes in output.

To summerize, the FA and the HCC optimized rules are robust to model uncertainty about financial frictions across the set of models considered here. Adopting these policy rules in all the model economies yields acceptable welfare costs in the alternative model economies with the costs being the lowest when following the HCC optimized rule featuring a strong response to changes in output and no interest rate smoothing.

### 3.4 Fault tolerance

The fault tolerance approach is proposed for the analysis of monetary policy robustness by Levin and Williams (2003). This is a method to evaluate sensitivity of the models to deviations from optimal policy. Specifically, it is suggested that all but one parameter values are fixed at their optimized values, while the remaining one is allowed to vary, such that welfare costs are evaluated for the range of parameter values.

Let  $\theta$  be the vector of the set of simple rule parameters  $\theta = \begin{pmatrix} \rho \\ \alpha_\pi \\ \alpha_y \end{pmatrix}$  and  $\hat{\theta}(A)$  denote the model  $A$  optimized simple rule. The fault tolerance approach consists in evaluating welfare costs  $\lambda$  according to (3.5) such that welfare costs are a function of  $\theta$ :  $\% \Delta \lambda = f(\theta)$ , where  $\theta_i$ ,  $i = \{1, 2, 3\}$  is allowed to vary, while  $\theta_j = \hat{\theta}_j(M)$ , for  $j \neq i$  where,  $M = \{BNK, FA, HCC\}$ .

Before discussing the results, it is important to take a notice of an extension to the original

fault tolerance methodology that I implement here. In the original formulation of Levin and Williams (2003) it is suggested to estimate welfare losses of deviations from the model's own optimized policy rule. In particular, for the model  $M_k$ ,  $k = \{1, 2, 3\}$  the following deviations are considered:  $\theta_i$  varies,  $\theta_j = \hat{\theta}_j(M_k)$ .

My extension consists in evaluating welfare costs of parameters deviations from all the optimized policy rules, not only for the model's own one. Specifically, for each model  $M_k$ ,  $k = \{1, 2, 3\}$  the analyzed deviations are: first,  $\theta_i$  varies,  $\theta_j = \hat{\theta}_j(M_k)$ , and also,  $\theta_i$  varies,  $\theta_j = \hat{\theta}_j(M_l)$ , where  $k \neq l$ . This extension allows to take into account all optimized policy rules in the search of the robust one. This enables, first, to determine the parameters of a robust policy rule (if there is one attainable), and second, to identify policies that could improve welfare across the set of models considered. By using this extension to the fault tolerance methodology I show how the BNK model optimized policy rule could be modified such that it becomes robust to model uncertainty.

The results of using the fault tolerance methodology with its extension are presented in the Appendix to this chapter. Allowing for changes of the value of  $\rho$  parameter in the BNK optimized rule leads to divergent welfare outcomes. Lower values of  $\rho$ , a rule that features lower degree of inertia, reduce welfare costs in the FA model (Figure 3.1 in the Appendix). However, losses in the HCC model are not sensitive to any changes in  $\rho$  parameter as long as other parameters take their BNK-optimized values  $\hat{\theta}(BNK)$  ( $\alpha_\pi = 3$  and  $\alpha_y = 0$ ): welfare costs are at their unacceptably high level of more than 7% for all the possible values of  $\rho$ . Thus, changing the degree of interest rate smoothing in the BNK optimal rule does not help to improve welfare in the HCC model.

Instead, the situation is different when changes of output coefficient in the BNK optimized rule are considered (Figure 3.3 in the Appendix). Increasing  $\alpha_y$  from its optimal value of 0 to 0.6 – 1.2 reduces welfare losses in the models with frictions to their acceptable levels: both FA and HCC economies generate welfare losses close to zero when  $\alpha_y$  lies on interval [0.6, 1.2]. Hence, by modifying BNK optimized rule a policymaker could attain robustness for the found set of values for output coefficient.

Increasing the value of  $\rho$  coefficient in the FA optimized rule from its optimal value of 0.165 up to 0.6 brings about reduction of welfare losses in the BNK model economy. At the same time welfare losses on the HCC and FA models don't increase much as a result of this change, i.e. the models with frictions are tolerant to higher degree of interest rate inertia. Thus, if the FA optimized policy rule is adopted by a policymaker, making interest rate more inertial would result in improvement of welfare across the set of the models. However, further increase of coefficient of interest rate inertia would result in sharp increase of welfare losses in the FA model - see Figure 3.4 in the Appendix.

Changing inflation and output coefficients in the FA optimized rule doesn't result in welfare costs decrease (Figures 3.5 and 3.6): optimal values of the FA rule generate the smallest possible welfare costs, thus, there is no need to modify them with the purpose of welfare improvement; changes in inflation and output coefficients  $\alpha_\pi$  and  $\alpha_y$  only lead to welfare deterioration.

Fault tolerance analysis of changes in HCC optimal policy rule gives similar results as deviations from the optimized values of the FA rule. Interest rate inertia coefficient  $\rho$  being increased up to 0.7 results in welfare improvement in all the models (Figure 3.7 in the Appendix). However, for the values  $\rho \geq 0.7$  welfare costs in FA economy increase up to unacceptable high levels, thus only values of  $\rho$  less than 0.7 are welfare improving. Deviations of  $\alpha_\pi$  and  $\alpha_y$  from their optimized values of the HCC policy rule don't lead to any improvement in welfare; the minimum welfare costs are achieved in all the models for the HCC rule parameter values fixed at their optimized values.

To conclude, fault tolerance analysis enables to ascertain whether changes of parameter values in optimized policy rules could lead to improvement of welfare. Modifying the BNK optimized rule by increasing its output coefficient to any value in the interval  $[0.6, 1.4]$  makes this rule robust. Though, the amended BNK rule is not optimal for any of the models, applying it in all the model economies entails acceptable levels of welfare losses. Besides, applying the fault tolerance methodology enables to find out whether deviations of parameter values in robust rules could improve welfare. Greater value of interest rate inertia coefficient in the optimized robust FA and HCC policy rules (up to 0.6 in the FA case and 0.7 in the HCC case) results in the welfare improvement in the BNK model.



### 3.5 Conclusion

This chapter demonstrates that financial frictions matter for robustness of monetary policy. It is shown that strict inflation targeting could be welfare detrimental in the models with financial frictions. When there is uncertainty about what financial factors are at work and thus it is not evident what type of frictions should be used in a reference model for monetary policy analysis, the basic New Keynesian model should not be used by a policymaker unless it is appropriately modified. I establish that the BNK optimized rule yields high welfare losses due to financial frictions present in alternative models. I show that the model with housing and collateral constraints is the most sensitive to following the BNK optimized policy rule: it suffers the highest welfare costs under this policy formulation. Policy rules optimized for the financial accelerator model and for the model with housing and collateral constraints deliver acceptable levels of welfare losses in all the alternative model economies and thus are robust to model uncertainty. Hence a policymaker minimizes the risk of welfare losses by using either of the models as a reference one to obtain an optimized policy rule.

I demonstrate in this chapter how by using the extended version of the fault tolerance approach suggested originally by Levin and Williams (2003) one can determine a specification of policy, which is robust to model uncertainty across the set of models. Higher degree of responsiveness to changes of output, i.e. sizable increase of output coefficient in the policy rule optimized for the basic New Keynesian model, results in this rule being robust as it delivers satisfactory welfare outcomes across all model economies.

A number of questions should be answered in order to have a strategy to address the issue of model uncertainty for the purposes of policymaking. First, it is crucial to establish, what models should be used in the set of alternative economy representations. As seen in the literature, for instance, in Cogley et al. (2011), Levine et al. (2008), Brock et al. (2003) and Levin and Williams (2003), a specification of robust policy is sensitive to the set of alternative models considered. Thus, it is critical to verify what models have to be accounted for in the quest of robust policy. Relevance of this point increases in light of development of many variants of models with divergent financial factors aiming to capture mechanisms conducive to economic distress. It is conceivable that not all alternative models should be considered as possible representations of economy when looking for a robust policy rule. Second, the analysis here could be extended by monetary policy rule incorporating other variables (in addition to responses to inflation, output and interest rate deviations). For example, policymaker could respond to changes in leverage ratio - this could improve stabilization properties of monetary policy rules in the models with financial factors. Another extension of this paper could be to analyse robustness with respect to other types of financial frictions, for example, disruptions of financial intermediation, asset prices bubbles, etc., as these factors could possibly affect the results regarding robustness obtained here. Additionally, Bayesian updating approach could be used, so that prior beliefs about the probabilities of each model being a true one and their updating, potentially endogenous priors, are incorporated in the analysis (as in Cogley et al., 2011 or Brock et al., 2007).

## 3.6 Appendix

### 3.6.1 Basic New Keynesian model

Equilibrium conditions following Walsh (2010). Variables without time subscripts denote their steady state values.

$$c_t^{-\sigma} = \beta * E_t(r_t * \frac{c_{t+1}^{-\sigma}}{\pi_{t+1}})$$

$$\chi * \frac{n_t^\eta}{c_t^{-\sigma}} = w_t$$

$$mc_t = \frac{w_t}{z_t}$$

$$1 = \omega * \pi_t^{\theta-1} + (1 - \omega) * p_t^{1-\theta}$$

$$x_{1,t} = c_t^{1-\sigma} * mc_t + \omega * \beta * x_{1,t+1} * \pi_{t+1}^\theta$$

$$x_{2,t} = c_t^{1-\sigma} + \omega * \beta * x_{2,t+1} * \pi_{t+1}^{\theta-1}$$

$$p_t = \frac{\theta}{\theta - 1} * \frac{x_{1,t}}{x_{2,t}}$$

$$y_t = z_t * n_t$$

$$y_t = c_t + g_t$$

$$\ln(z_t) = \rho_z \ln(z_{t-1}) + \epsilon_{z,t}$$

$$\ln(\frac{g_t}{g}) = \rho_z \ln(\frac{g_{t-1}}{g}) + \epsilon_{g,t}$$

$$\ln(\frac{r_t}{r}) = \rho \ln(\frac{r_{t-1}}{r}) + \alpha_\pi \ln(\frac{\pi_t}{\pi}) + \alpha_y \ln(\frac{y_t}{y}) + \epsilon_{r,t}$$

Representative agent utility function:

$$U(C_t, N_t) = \frac{c_t^{1-\sigma}}{1-\sigma} - \chi * \frac{n_t^{1+\eta}}{1+\eta}$$

Table 3.5: Variables and parameters, BNK model

Description	Notation
Household consumption	$c_t$
Household labour supply	$n_t$
Marginal costs	$mc_t$
Government spending	$g_t$
Output	$y_t$
Productivity	$z_t$
Real aggregate price level	$p_t$
Inflation	$\pi_t$
Gross nominal interest rate	$r_t$
Real wage	$w_t$
Productivity shock innovation	$\epsilon_{z,t}$
Shock to government spending innovation	$\epsilon_{g,t}$
Monetary policy shock innovation	$\epsilon_{r,t}$
Auxiliary variables	$x_{1,t}, x_{2,t}$
Coefficients in the interest rate policy rule on lagged interest rate, inflation and output	$\rho, \alpha_\pi, \alpha_y$

Table 3.6: Calibrated parameter values, BNK model

Description	Parameter	Value
Discount rate	$\beta$	0.9902
Relative risk aversion	$\sigma$	2
Weight of labour in the utility function	$\chi$	1
Labour supply aversion	$\eta$	3
Calvo parameter	$\omega$	0.75
Price elasticity of demand for each good variety	$\theta$	6
Steady state share of government consumption	$g$	0.17
Persistence of productivity shocks	$\rho_z$	0.8556
Persistence of government spending shocks	$\rho_g$	0.87
Standard deviation of innovation to productivity shock	$\sigma_z$	0.0064
Standard deviation of innovation to government spending shock	$\sigma_g$	0.016
Standard deviation of innovation to monetary policy shock	$\sigma_r$	0.0031

Note: The driving forces  $g_t$  and  $z_t$  are calibrated based on estimations of Schmitt-Grohe and Uribe (2006). Monetary policy shock innovation is calibrated based on estimation of Ireland (2004).

### 3.6.2 Financial accelerator model

Equilibrium conditions, following Christensen and Dib (2008). Hatted variables denote log-deviations of these variables their from steady state values. Variables without time subscripts denote steady state values of these variables.

$$\begin{aligned}
((1 - \gamma) * \lambda * c - 1) * \hat{c}_t &= \gamma * \hat{\lambda} + \lambda * m * (r - 1) / r * (\hat{b}_t + (\gamma - 1) * \hat{m}_t) - \gamma * \hat{e}_t \\
\gamma * \hat{r}_t / (r - 1) &= \hat{b}_t + \hat{c}_t - \hat{m}_t \\
h * \hat{h}_t &= (1 - h) * (\hat{w}_t + \hat{\lambda}_t) \\
\hat{y}_t &= \alpha * \hat{k}_t + (1 - \alpha) * \hat{h}_t + (1 - \alpha) * \hat{A}_t \\
\hat{y}_t * y &= c * \hat{c}_t + i * \hat{i}_t \\
\hat{w}_t &= \hat{y}_t + \hat{\epsilon}_t - \hat{h}_t \\
\hat{z}_t &= \hat{y}_t + \hat{\epsilon}_t - \hat{k}_t \\
\hat{\mu}_t &= \hat{m}_t - \widehat{m_{t-1}} + \hat{\pi}_t \\
\hat{f}_t &= z / f * \hat{z}_t + (1 - \delta) / f * \hat{q}_t - \widehat{q_{t-1}} \\
\hat{q}_t &= \chi * (\hat{i}_t - \hat{k}_t) - \hat{x}_t \\
\hat{\pi}_t &= \beta * \pi_{t+1} + (1 - \beta * \phi) * (1 - \phi) / \phi * \hat{\epsilon}_t \\
\widehat{\lambda_{t+1}} &= \hat{\lambda}_t - \hat{r}_t + \pi_{t+1} \\
\widehat{k_{t+1}} &= \delta * \hat{i}_t + \delta * \hat{x}_t + (1 - \delta) * \hat{k}_t \\
\widehat{f_{t+1}} &= \hat{r}_t - \widehat{\pi_{t+1}} + \psi * (\hat{q}_t + \widehat{k_{t+1}} - \widehat{n_{t+1}}) \\
\widehat{n_{t+1}} / (v * f) &= k / n * \hat{f}_t - (k / n - 1) * (\widehat{r_{t-1}} - \hat{\pi}_t) - \psi * (k / n - 1) * (\hat{k}_t + \widehat{q_{t-1}}) + (\psi * (k / n - 1) + 1) * \hat{n}_t \\
\ln\left(\frac{r_t}{r}\right) &= \rho \ln\left(\frac{r_{t-1}}{r}\right) + \alpha_\pi \ln\left(\frac{\pi_t}{\pi}\right) + \alpha_y \ln\left(\frac{y_t}{y}\right) + \epsilon_{r,t} \\
\hat{e}_t &= \rho_e \widehat{e_{t-1}} + \epsilon_{e,t} \\
\hat{b}_t &= \rho_b \widehat{b_{t-1}} + \epsilon_{b,t} \\
\widehat{A}_t &= \rho_A \widehat{A_{t-1}} + \epsilon_{A,t} \\
\hat{x}_t &= \rho_x \widehat{x_{t-1}} + \epsilon_{x,t}
\end{aligned}$$

To set financial accelerator mechanism inactive elasticity of external financial premium to firm leverage ratio is appointed to be equal to zero:  $\psi = 0$ .

Representative agent utility function:

$$u(.) = \gamma \frac{e_t}{\gamma - 1} \ln(c_t^{\frac{\gamma-1}{\gamma}} + b_t^{\frac{1}{\gamma}} m_t^{\frac{\gamma-1}{\gamma}}) + \eta \ln(1 - h_t)$$

Table 3.7: Variables and parameters, FA model

Description	Notation
Household consumption	$c_t$
Household labour supply	$h_t$
Net worth	$n_t$
Government spending	$g_t$
Output	$y_t$
Productivity	$A_t$
Gross nominal interest rate	$r_t$
Real wage	$w_t$
Lagrange multiplier	$\lambda_t$
Real money balances	$m_t$
Aggregate capital	$k_t$
Aggregate investment	$i_t$
Lagrange multiplier associated with production function	$\epsilon_t$
Real marginal productivity of capital	$z_t$
Money growth	$\mu_t$
Inflation	$\pi_t$
Real interest rate on external borrowed funds	$f_t$
Price of capital	$q_t$
Weight of preference for consumption	$e_t$
Money demand	$b_t$
Investment specific productivity	$x_t$
Preference shock innovation	$\epsilon_{e,t}$
Money demand shock innovation	$\epsilon_{b,t}$
Investment specific shock innovation	$\epsilon_{x,t}$
Productivity shock innovation	$\epsilon_{A,t}$
Shock to government spending innovation	$\epsilon_{g,t}$
Monetary policy shock innovation	$\epsilon_{r,t}$
Coefficients in the interest rate policy rule on lagged interest rate, inflation and output	$\rho, \alpha_\pi, \alpha_y$

Table 3.8: Calibrated parameter values, FA model

Description	Parameter	Value
Discount rate	$\beta$	0.9902
Gross steady state risk premium	S	1.0075
Gross steady state inflation rate	$\pi$	1.0079
Intermediate goods elasticity of substitution	$\theta$	6
Constant elasticity of substitution between consumption and real money balances	$\gamma$	0.0598
Weight of leisure in the utility function	$\eta$	1.315
Price stickiness parameter	$\phi$	0.7418
Constant associated with money demand shock	b	0.062
Capital adjustment costs parameter	$\chi$	0.5882
Capital share	$\alpha$	0.3384
Depreciation rate	$\delta$	0.025
Steady state ratio of capital to net worth	k/n	2
Probability of survival of entrepreneurs	$v$	0.9728
Elasticity of external finance premium to firm leverage ratio	$\psi$	0.042
Persistence of productivity shocks	$\rho_A$	0.7625
Persistence of money demand shock	$\rho_b$	0.7206
Persistence of preference shock	$\rho_e$	0.6156
Persistence of investment efficiency shock	$\rho_x$	0.6562
Standard deviation of innovation to productivity shock	$\sigma_A$	0.0096
Standard deviation of innovation to money demand shock	$\sigma_b$	0.0103
Standard deviation of innovation to preference shock	$\sigma_e$	0.0073
Standard deviation of innovation to investment efficiency shock	$\sigma_x$	0.0331
Standard deviation of innovation to monetary policy shock	$\sigma_r$	0.0031

Note: Calibration is based on estimations of Chistensen and Dib (2008).

### 3.6.3 Model with housing and collateral constraints

Equilibrium conditions following Iacoviello (2005). Hatted variables denote log-deviations of these variables from their steady state values. Variables without time subscripts denote steady state values of these variables.

$$\begin{aligned}
\hat{Y}_t &= c/Y * \hat{c}_t + c'/Y * \hat{c}'_t + c''/Y * \hat{c}''_t + I/Y * \hat{I}_t \\
\hat{c}'_t &= \widehat{c'_{t+1}} - \widehat{r r_t} \\
\hat{I}_t - \hat{K}_{t-1} &= \gamma * (\widehat{I_{t+1}} - \hat{K}_t) + (1 - \gamma * (1 - \delta)) / \psi * (\widehat{Y_{t+1}} - \widehat{X_{t+1}} - \hat{K}_t) + 1 / \psi * (\hat{c}_t - \widehat{c_{t+1}}) \\
\hat{q}_t &= \gamma_e * \hat{q}_{t+1} + (1 - \gamma_e) * (\widehat{Y_{t+1}} - \widehat{X_{t+1}} - \hat{h}_t) - m * \beta * \widehat{r r_t} - (1 - m * \beta) * \Delta \widehat{c_{t+1}} - \phi_e * (\Delta \hat{h}_t - \gamma \Delta \widehat{h_{t+1}}) \\
\hat{q}_t &= \gamma_h * \hat{q}_{t+1} + (1 - \gamma_h) * (\widehat{J_{t+1}} - \widehat{h''_t}) - m'' * \beta * \widehat{r r_t} - (1 - m'' * \beta) * (\hat{c}'_t - \omega * \widehat{c''_{t+1}} - \phi_h * (\Delta \hat{h}_t - \beta'' \Delta \widehat{h''_{t+1}})) \\
\hat{q}_t &= \beta * \hat{q}_{t+1} + (1 - \beta) * \widehat{J_{t+1}} + i * \hat{h}_t + i'' * \widehat{h''_t} + \hat{c}'_t - \beta * \widehat{c'_{t+1}} + \phi_h / h' * (h \Delta \hat{h}_t + h'' \Delta \widehat{h''_t} - \beta * h * \Delta * \widehat{h_{t+1}} - \beta h'') \\
\hat{b}_t &= \widehat{q_{t+1}} + \hat{h}_t - \widehat{r r_t} \\
\hat{b}''_t &= \widehat{q_{t+1}} + \hat{h}''_t - \widehat{r r_t} \\
\hat{Y}_t &= \frac{\eta}{\eta - (1 - v - \mu)} * (\hat{A}_t + v * \widehat{h_{t-1}} + \mu * \widehat{K_{t-1}}) - \frac{1 - v - \mu}{\eta - (1 - v - \mu)} * (\widehat{X_t} + \alpha * \hat{c}'_t + (1 - \alpha) * \hat{c}''_t) \\
\hat{\pi}_t &= \beta * \pi_{t+1} - \kappa * \widehat{X_t} + \hat{u}_t \\
\hat{K}_t &= \delta * \hat{I}_t + (1 - \delta) * \widehat{K_{t-1}} \\
b/Y * \hat{b}_t &= c/Y * \hat{c}_t + q * h/Y \Delta \hat{h}_t + I/Y * \widehat{I - t} + Rb/Y (\widehat{R_{t-1}} + \widehat{b_{t-1}} - \hat{\pi}_t) - (1 - s' - s'') (\hat{Y}_t - \widehat{X_t}) \\
b''/Y * \hat{b}''_t &= c''/Y * \hat{c}''_t + q * h''/Y \Delta \hat{h}''_t + Rb''/Y (\widehat{R_{t-1}} + \widehat{b''_{t-1}} - \hat{\pi}_t) - s'' (\hat{Y}_t - \widehat{X_t}) \\
\ln(\frac{r_t}{r}) &= \rho \ln(\frac{r_{t-1}}{r}) + \alpha_\pi \ln(\frac{\pi_t}{\pi}) + \alpha_y \ln(\frac{y_t}{t}) + \epsilon_{r,t} \\
\hat{j}_t &= \rho_j * \widehat{j_{t-1}} + \epsilon_{j,t} \\
\hat{u}_t &= \rho_u * \widehat{u_{t-1}} + \epsilon_{u,t} \\
\hat{A}_t &= \rho_A * \widehat{A_{t-1}} + \epsilon_{\hat{A},t} \\
\omega &= (\beta'' - m'' \beta'') / (1 - m'' \beta) \\
i &= (1 - \beta) h / h' \\
i'' &= (1 - \beta) h'' / h' \\
\gamma_h &\equiv \beta'' + m'' (\beta - \beta'') \\
\widehat{r r_t} &\equiv \widehat{R_t} - E_t \widehat{\pi_{t+1}} \\
\gamma_e &\equiv m * \beta + (1 - m) * \gamma \\
s' &\equiv (\alpha(1 - \mu - v) + X - 1) / X
\end{aligned}$$

$$s'' \equiv (1 - \alpha)(1 - \mu - v)/X$$

To close the effects of collateral constraints, housing/consumption margin conditions of entrepreneurs and impatient households are modified. so that the asset price channel is inactive:

$$\hat{q}_t = \gamma_e * q_{t+1} + (1 - \gamma_e) * (\widehat{Y_{t+1}} - \widehat{X_{t+1}} - \hat{h}_t) - \widehat{c'_{t+1}} * (\gamma + 1 - \gamma_e) + \hat{c}_t - \phi_e * (\hat{h}_t - \widehat{h_{t-1}} - \gamma * (\widehat{h_{t+1}} - \hat{h}_t))$$

$$\hat{q}_t = \beta'' * q_{t+1} + (1 - \gamma_h) * (\hat{j}_t - \widehat{h''_t}) - \widehat{c''_{t+1}} * \beta'' + \hat{c''_t} - \phi_h * (\widehat{h''_t} - \widehat{h''_{t-1}} - \beta'' * (\widehat{h''_{t+1}} - \widehat{h''_t}))$$

Representative agent utility function:

$$u(.) = \ln(c'_t) + j \ln(h'_t) - (L'_t)^\eta / \eta$$



Table 3.9: Variables and parameters, HCC model

Description	Notation
Output	$y_t$
Entrepreneurs', patient and impatient households' consumption	$c_t, c'_t, c''_t$
Patient and impatient households' labour supply	$L'_t, L''_t$
Entrepreneurs', patient and impatient households' holding of housing	$h_t, h'_t, h''_t$
Aggregate investment	$i_t$
Aggregate capital	$k_t$
Markup	$X_t$
Price of housing	$q_t$
Real borrowing, lending	$b_t$
Inflation	$\pi_t$
Gross nominal interest rate	$r_t$
Preference for housing	$j_t$
Productivity	$A_t$
Inflation shock	$u_t$
Preference for housing shock innovation	$\epsilon_{j,t}$
Cost-push shock innovation	$\epsilon_{u,t}$
Productivity shock innovation	$\epsilon_{A,t}$
Monetary policy shock innovation	$\epsilon_{r,t}$
Auxiliary variables	$\omega_t, i_t, i'_t, i''_t, \gamma_h$
Ex ante real interest rate	$rr_t$
Income shares of patient and impatient households	$s', s''$
Slope of Phillips curve	$\kappa$
Coefficients in the interest rate policy rule on lagged interest rate, inflation and output	$\rho, \alpha_\pi, \alpha_y$

Table 3.10: Calibrated parameter values, HCC model

Description	Parameter	Value
Discount rate of patient households	$\beta$	0.99
Discount rate of impatient households	$\beta''$	0.98
Discount rate of entrepreneurs	$\gamma$	0.95
Weight on housing services	$j$	0.1
Labour supply aversion	$\eta$	1.01
Variable capital share	$\mu$	0.03
Elasticity of output to housing	$v$	0.03
Housing adjustment cost	$\phi_e, \phi_h$	0
Variable capital adjustment costs	$\psi$	2
Variable depreciation rate	$\delta$	0.03
Calvo parameter	$\theta$	0.75
Patient households wage share	$\alpha$	0.64
Loan-to-value entrepreneur	$m$	0.89
Loan-to-value household	$m''$	0.55
Steady state gross markup	$\chi$	1.05
Persistence of technology shock	$\rho_A$	0.03
Persistence of housing preference shock	$\rho_j$	0.85
Persistence of inflation shock	$\rho_u$	0.59
Standard deviation of innovation to technology shock	$\sigma_A$	2.24
Standard deviation of innovation to housing preference shock	$\sigma_j$	24.89
Standard deviation of innovation to inflation shock	$\sigma_u$	0.17
Standard deviation of innovation to monetary policy shock	$\sigma_r$	0.29

Note: Calibration is based on estimations of Iacoviello (2005).

### 3.6.4 Fault tolerance analysis

Figure 3.1: Fault tolerance to deviations of  $\rho$  parameter in the BNK optimized rule

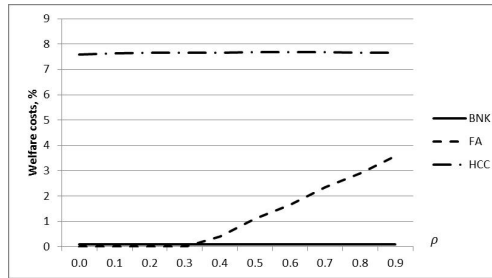


Figure 3.2: Fault tolerance to deviations of  $\alpha_\pi$  parameter in the BNK optimized rule

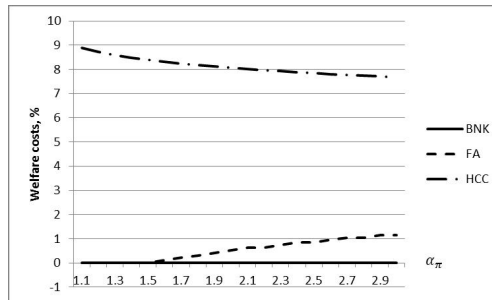


Figure 3.3: Fault tolerance to deviations of  $\alpha_y$  parameter in the BNK optimized rule

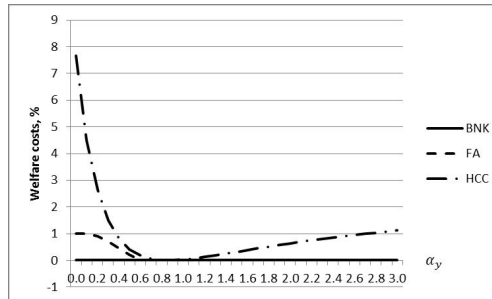


Figure 3.4: Fault tolerance to deviations of  $\rho$  parameter in the FA optimized rule

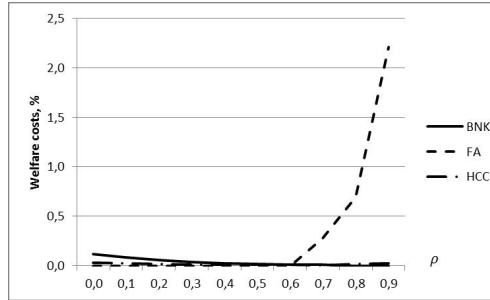


Figure 3.5: Fault tolerance to deviations of  $\alpha_\pi$  parameter in the FA optimized rule

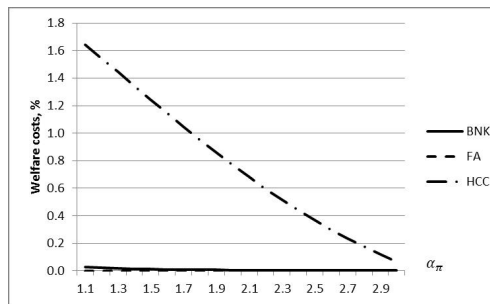


Figure 3.6: Fault tolerance to deviations of  $\alpha_y$  parameter in the FA optimized rule

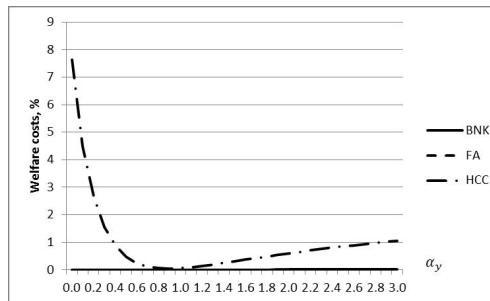


Figure 3.7: Fault tolerance to deviations of  $\rho$  parameter in the HCC optimized rule

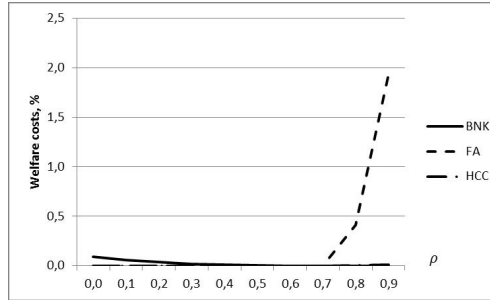


Figure 3.8: Fault tolerance to deviations of  $\alpha_\pi$  parameter in the HCC optimized rule

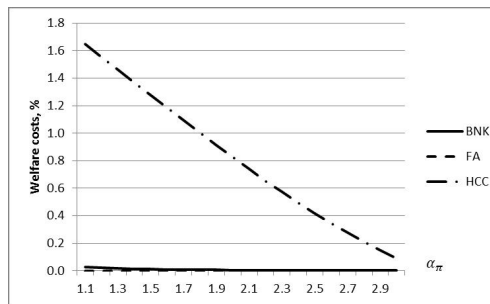
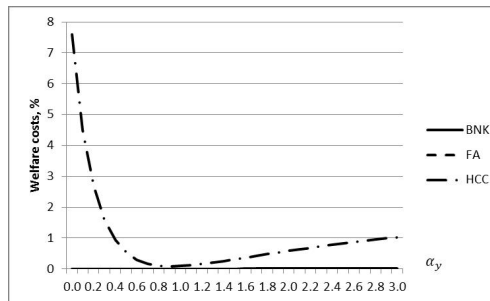


Figure 3.9: Fault tolerance to deviations of  $\alpha_y$  parameter in the HCC optimized rule



# Concluding remarks

I used several research approaches to analyze the relationship between uncertainty and financial frictions. Chapter 1 examines the impact of economic uncertainty on asset portfolio allocation of the banking sector empirically and demonstrates that a positive shock to uncertainty induces commercial banks to increase the share of safe assets, while reducing the share of risky business lending in their portfolios. It also presents evidence supporting the existence of bank lending channel of monetary policy. Chapter 2 constructs a DSGE model with a portfolio-optimizing banking sector and introduces the precautionary mechanism that brings about increase of risk premium to self-insure against future reductions of profitability following uncertainty shocks. Chapter 3 shows that when there is uncertainty about what type of frictions is at work, a policymaker exposes economy to risks of significant welfare losses by using a reference model without frictions as economy representation. Hence, it is important that financial frictions are accounted for in the monetary policy analysis.

In this section I set out several suggestions for further study to improve our understanding of macroeconomic effects of uncertainty under frictions related to banking sector activities.

- One can investigate what implications does the presence of uncertainty and changes in volatility have for the design of optimal monetary policy. For that I propose that the theoretical model presented in chapter 2 is employed after being amended to incorporate parameter time variation. I suggest that while modelling the banking sector balance sheet, novel balance sheet items are introduced, in particular, bank equity capital and bank reserves. With this structure of balance sheets, preferences of banks could be modelled as linear subject to capital adequacy and leverage requirements. This will allow to take into account the risk of insolvency of banks and investigate the consequences of introduction of macroprudential policy and its interaction with monetary policy.
- The zero lower bound is not reached in the model simulations in chapter 2. However, it would be interesting to see whether and how the introduction of zero lower bound would change the theoretical result of the significant effect of uncertainty shock on aggregate investment and output. In the current model setup the conventional monetary policy supports output after uncertainty shock by the interest rate reduction. Assuming that nominal interest rates cannot be decreased might change the results. Specifically, if nominal interest rate is at the lower point at the time of the shock and conven-

tional monetary policy cannot be effectively used, uncertainty shock may have a larger impact.

- As a robustness check of results obtained in chapter 1, one can use an alternative methodology and identification to estimate the effects of elevated uncertainty and study the effects of monetary policy on the volumes of credit by using the time-varying parameter VAR with stochastic volatility. The characteristic feature of this approach is that changes in economic uncertainty can be modelled endogenously as time-varying volatility of macroeconomic and credit variables, without the reference to any specific measure of macro or microeconomic uncertainty. This approach would allow to accommodate the structural changes in relationships between the key credit and macro variables, identified in Chapter 1, in a flexible and robust way. Time variation of the variance covariance matrix of innovations would enable to model changes in policy, in underlying economic structure and in their interaction.

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